London's Warming: The Impacts of Climate Change on London

london'swarming

The Impacts of Climate Change on London

Technical Report

A High Profile Launch for London's First Climate Change Study

The Mayor of London Ken Livingstone and Environment Minister Michael Meacher launched London's Warming on 24 October 2002.

The launch event was very successful, attracting a large number of people from a wide range of sectors. Many individuals attended who had not previously been involved in the Climate Impacts study but recognised that climate change is an issue that will become increasingly important in the years to come.

At the Launch the Environment Minister said "The UK is leading the way in identifying the effects which climate change will have on all parts of the country, including our capital city. Some climate change is now inevitable, so we are going to have to adapt."

While the Mayor of London pointed out the particular issues that London will have to face, saying "The size of this city's population means that there's already huge pressure on our resources, so we have to plan properly and strategically to deal with these new demands. This report is the start of that process."

If you want to be part of that process please contact the London Climate Change Partnership at climatechange@london.gov.uk.

London Climate Change Partnership

A Climate Change Impacts in London Evaluation Study

Final Report

November 2002

Certificate No. FS 13881

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Acknowledgements

The London Climate Change Partnership, a group of stakeholders originally convened by the Government Office for London in July 2001, commissioned this work to take a first look at the impacts that climate change will have on our capital city. The members of the partnership are: The Greater London Authority (GLA), Government Office for London, the Association of London Government (ALG), the Housing Corporation, the Environment Agency, the Assocaition of British Insurers (ABI), the London Development Agency (LDA), Thames Water, the London Electricity Group, the Corporation of London, St. George Plc., Transport for London (TfL), UK Climate Impacts Programme (UKCIP), the London Sustainabiolity Exchange and the Thames Gateway Partnership. A more comprehensive list of organisations who have taken part in meetings related to this study can be found in Appendix A.

This study wsas carried out by a project consortium consisting of Entec UK Ltd, the Tyndall centre for Climate Change research, Meetroeconomica, Dr.Rob Wilby of King's college London and Professor David Crichton, an independent consultant.

The main contributors were: Simon Clarke, Jim Kersey and Emily Trevorrow of Entec UK LTd.; Rob Wilby of King's College, London; Simon Shackley, John Turnpenny and Andy Wright of the Tyndall Centre; Alistair Hunt of Metroeconomica; and David Crichton.

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Contents

Executive Summary

This study is the first step in understanding what may happen as a result of possible future climate change in London. It was commissioned by the Greater London Authority (the GLA), acting as an agent for the London Climate Change Partnership and has been written by a team led by Entec UK Ltd, comprising Dr. Rob Wilby (Kings' College London), the Tyndall Centre for Climate Change Research, Metroeconomica and Professor David Crichton (Independent Consultant).

The overall objective for the study was to "*outline the threats and opportunities presented by climate change, and start to address the responses needed*". More specifically this study has aimed to provide an overview of the existing information on the impacts of climate change on the environment and the economy and, to elucidate the social impacts of climate change largely based on existing reviews, research and monitoring studies within and outside of London. The study findings have been discussed in context with existing policies and strategies for London and recommendations for further work made accordingly.

Pivotal to the study has been 'stakeholder engagement' a broad term used to encompass (*inter alia*) the processes of: raising awareness amongst stakeholders; involving stakeholders; stakeholder consultation, and; consensus building amongst stakeholders about the likely direction and level of climate change in London and the impacts of such change on London, its population and businesses. Stakeholder engagement has been addressed in several ways by this project but primarily through a workshop setting.

There are two study reports. This report, the Technical Report, describes in detail the study's findings and is aimed at the more specialised reader and those involved in more detailed planning. A summary report has also been produced that presents the general findings from the study and is aimed at the general reader and policy makers.

The UK Climate Impacts Program (UKCIP) has published four scenarios (Low emissions, Medium-Low emissions, Medium-High emissions and High emissions) of future climates for the 2020's, 2050's and 2080's at a resolution of 50 km^2. These scenarios form the basis for impact analysis in this study. As well as existing published information and key input from a number of stakeholders consulted, the scenarios have been used to predict what impacts climate change is likely to have on London.

Climate change may exacerbate the urban heat island effect (a term used to describe the fact that the temperature of London at its centre is several degrees higher than at its edges; this is because London is a fairly dense, urban settlement and heat emitted from buildings and the characteristics of the airflow contribute to this temperature profile) with resulting impacts of increased summer heat stress and mortality, higher temperatures on the London underground and higher rates of household waste decay.

Further statistical analyses of the UKCIP climate scenarios have been undertaken to predict the specific environmental impacts of climate change on London whilst recognising that certain scientific uncertainties exist. Key environmental impacts identified within London relate to:

- Flood risk - London is vulnerable to three main types of flooding: the inundation of floodplains by river water, local flooding when the drainage network is overwhelmed by intense rainfall, and by tidal surges in the Thames. Climate change could adversely affect all three with the latter leading to more frequent operation of the Thames Barrier.

- Water resources - reduction in summer soil moisture (affecting plants and animals and their habitats), lower summer and higher winter flows in rivers (with lower summer flows aggravating water quality problems, especially following heavy storms) and increased domestic water demand.
- Air quality - a reduction in air quality leading to possible health problems and potential deleterious effects on urban trees and urban fabric.
- Biodiversity - changes in the distribution of species and the places they inhabit.

In relation to social impacts, the study found that:

- on balance the social impacts of climate change upon London are probably more negative than positive.
- there are, however, some potentially significant benefits for a number of sectors such as tourism and leisure where increased temperatures could attract more visitors to London.
- there are some but, in the majority of cases, fairly small benefits for a number of sectors including transport (less 'cold weather' disruption), housing (warmer winters should reduce winter fuel bills), history & cultural legacy (changes in flow patterns in the river Thames potentially uncovering more archaeological remnants), jobs (e.g. opportunities in the tourist industry and in emergency services and urban planning and design), health (fewer cold-weather related illnesses) although these are often offset by larger negative impacts.
- the more negative impacts arising from housing, redevelopment, built environment, health, clean city (relating to air quality and decay of household rubbish), cost of living (including insuring properties) and open and green spaces are all uncertain, in part because the scale and precise character of the impact depends on the adjustment and adaptation responses. However, most of the larger negatives are attributable to potentially increased flooding, greater incidence of summer heat waves, exacerbation of existing air pollution problems and increased pressures upon open and green spaces from water shortages and greater water use.
- suitable adaptation policies and management could limit the incidence of the most negative impacts.

The study has also identified the following economic impacts for London:

- the increased flood risk to areas of London, already vulnerable to river and drainage flooding, from higher rainfall intensities predicted in the climate change scenarios, poses a threat to many economic assets, including property and communication infrastructure.
- flood risk to buildings and infrastructure - along with changing atmospheric conditions associated with a warmer climate - present immediate challenges in

building and urban design. These climate change issues do not relate only to London.

- The London insurance industry, as one of the three largest global insurance centres, is particularly exposed to an increased volume of claims from business and domestic customers that are likely to occur in the event of higher and more extreme wind storms and flood events. Since UK insurers offer greater insurance protection for weather-related damage than their competitors elsewhere, they are, consequentially, more exposed to climate change effects.

- the economic costs of weather-related disruption to London transport systems was the economic impact most widely identified by stakeholders in the consultation process.

- the net balance of change in energy demand as a consequence of climate change in London is not clear. The supply infrastructure network is vulnerable to windstorms and clay shrinkage. The economic impacts of disruption to the power supply for extended periods has not been estimated in quantitative terms but is believed to be significant.

- manufacturing is subject to disruption of raw materials (e.g. food stuffs) that are supplied from parts of the world adversely impacted by climate change.

- revenues from tourism may increase as London - and the UK - becomes a more attractive destination in summer relative to those in Southern Europe and elsewhere that are likely to suffer from adverse climate change impacts. However, more trips may be taken from London to escape uncomfortably high temperatures due to heat island impacts.

Increased general awareness of potential and actual climate change impacts in London is likely to focus policy makers minds on the need to mitigate and adapt to such impacts locally and globally in the future. Indeed, many of the key strategic and policy processes have begun to consider the potential impacts of climate change. Awareness of climate change issues amongst stakeholders involved in this study was high and is accelerating. However, most of the strategy and policy responses are of a scoping nature and more work needs to be done to begin to quantify the potential climate change impacts and adaptation options at the local level including impact on water resources, flooding, water quality, settlement patterns, employment, working conditions, open spaces, infrastructure, economic sectors, biodiversity, economic sectors, health and the built environment.

1. Setting the Scene

1.1 Background and Objectives

This study is the first stage in trying to understand what may happen because of possible future climate change in London. It was commissioned by the Greater London Authority (the GLA), acting as an agent for the London Climate Change Partnership (a stakeholder group which has evolved from a meeting originally convened by the Government Office for London to discuss climate change in London in July 2001; a list of organisations that have taken part in meetings of the Partnership from 2001 onwards given in Appendix B). The study has been undertaken by a project consortium consisting of Entec UK Ltd, Dr. Rob Wilby (Kings' College London), the Tyndall Centre for Climate Change Research, Metroeconomica and Professor David Crichton (Independent Consultant).

The overall objectives for the study, as stated in the original tender documents were as follows:

> *"The study should outline the threats and opportunities presented by climate change, and start to address the responses needed. Investigating the policies and programmes needed to adapt to climate change in detail will be the subject of a subsequent (Stage two) study."*

This stage one study has also provided a platform for addressing the principal aims of the London Climate Change Partnership, which are:

1. To provide an overview of the best current information on the likely climate change scenarios for London.
2. To provide an overview of the existing information on the impacts of climate change on the environment and the economy and, to elucidate the social impacts of climate change largely based on existing reviews, research and monitoring studies within and outside the region.
3. To build a consensus view among key stakeholders about the likely direction and level of climate change in London and to assess the impacts of such change on London, its population and businesses.
4. To provide relevant input to ensure that policy responses are appropriate to the needs of London's population and economy.
5. To raise awareness amongst London institutions, businesses and communities that might otherwise not be aware of the implications of climate change and, in this way, ensure an increased understanding of the common issues faced by all of London in the event of various climate change outcomes.
6. To make proposals for further research and information collection to develop a better understanding of the type and extent of potential impacts.
7. To disseminate the results of the study effectively to those who need to take action.

The following sections address these aims.

There are two study reports. This report, the Draft Technical Report, describes in detail the study's findings and is aimed at the more specialised reader and those involved in more detailed planning.

1.2 Why London is Different

There are several features that distinguish this London study from other regional climate change studies:

- This is the first UK climate change impacts study with a distinctly urban focus. As a result, it has identified a number of climate change impacts that have received less attention in previous regional studies - such as impacts on air quality, transport infrastructure, buildings and the financial sector. As an increasing proportion of the world's population lives in cities, how the world's major cities are affected becomes increasingly important;
- London is not only the capital of the UK but a major world city. Changes to the world's climate will affect all parts of our globe. This will fundamentally affect the environmental, economic, social and political drivers that influence London;
- The Urban Heat Island effect exacerbates many impacts of climate change in London;
- Climate change impacts on buildings and the built environment, water resources, transport, parks and gardens, air pollution and tourism, are all exacerbated in London compared to other UK cities and regions. A population density twice that of most other UK cities exerts strong pressures upon these resources, systems and sectors;
- London's population has a diverse social structure and climate change will be likely to affect vulnerable social groups disproportionately (for example those on lower incomes may be more significantly affected).

1.3 Report Structure

This report starts by defining climate change and describing the baseline climate and environmental conditions in London (Section 1 and 2 respectively). This baseline provides the platform for subsequent discussions of regional climate change scenarios (Section 4) and associated environmental, social and economic impacts (Sections 5 to 7 respectively). This structure reflects the project methodology (see Appendix C) whereby environmental, social and economic impacts of climate change on London were addressed as three discreet (but related) workstreams involving key stakeholder workshop discussions. For this reason climate change issues such as flooding appear separately within each of Sections 5 to 7. However, Section 8 provides an overall summary of climate change impacts and possible adaptation options by combining impacts from all workstreams. Section 8 also addresses climate change in relation to policy issues relating to London and also provides recommendations for further research. Overall study conclusions are presented in Section 9.

It should be drawn to the attention of the reader that there are a number of climate change related issues for which little published information was available, or they were not considered as high priority issues by the stakeholders involved in this study, or there was neither the time nor the resources available to cover the issues. Such issues include areas such as infrastructure and food supply. These issues are covered in the report as they arise and have not been drawn out specifically for detailed consideration. However, the LCCP would welcome any comments relating to these and any other issues discussed within this report. It should also be noted that some issues will be found in more than one section.

2. What is Climate Change?

2.1 Climate Change – An Introduction

The earth's climate has been changing throughout its history and, until now, this has been mostly due to natural causes.

The atmosphere maintains the earth's temperature range by trapping a certain amount of the incoming energy from the Sun. The amount of energy that is trapped depends on the proportion of different gases in the atmosphere, which in turn determines the earth's temperature. A particular mixture of gases maintains the temperature within the range that supports life. Changes in the proportion of gases can alter the earth's temperature and hence weather patterns which are also influenced by the earth's geography (oceans, mountains, land masses etc). Thus the atmosphere needs a certain proportion of greenhouse gases (called the greenhouse gas concentration) in order to maintain an acceptable temperature range and hence support life.

There are concerns that because human activities have led to an increase in the levels of greenhouse gases in the atmosphere, the climate is changing beyond its natural variability. Climate change studies try to understand these changes and how they could affect us. This is done by looking at historical meteorological measurements, such as temperature and rainfall, and looking for changes beyond what can be considered natural. Computer based models are then run that try to describe the behaviour of global weather system due to increases in greenhouse gas levels. This is a complex task, as no model can hope to fully describe what is happening or could possibly happen with the weather. However the models are improving and are beginning to be able to more accurately describe what has been recorded historically and thus scientists are becoming more confident that such models are able to predict future changes. These models produce a range of possible events or scenarios, as there is no exact answer to what may happen with the climate. They produce estimates of future climate such as rainfall and temperature. This information can then be used to estimate what the impacts of climate change could be such as the effect on water resources and flooding. Less rainfall could reduce water resources. This in turn could affect agriculture, industry and domestic supplies. More rainfall could increase flooding, leading to damage to buildings and land. Changes in temperature could lead to changes in agriculture with different types of crops being grown and changes in the length of the growing and harvesting season. Many animal and plant species are sensitive to climatic factors, so changes in temperature and rainfall could also affect flora and fauna.

So, the scenarios can be used to help plan future programmes that may be affected by climate change such as where people live, the need for flood defence and water storage. However, climate change is not the only change that is happening. There are other changes brought about by social and economic trends. In some cases climate change may have only a minor impact and in others it may be more significant. In some cases climate changes may be beneficial and in other it may be adverse. Therefore consideration of possible future climate changes should be undertaken as part of the consideration of the wide range of issues that may affect organisations and people in the future.

In this study historical measurements of the London climate are examined to try to identify any trends in climate changes. Computer models have also been run to describe a range of possible scenarios for climate change in the future. The potential impacts of these climate changes are also described. These are presented in the following sections. The first section describes the evidence for climate change at the international and national levels and the organisations that have been set up to monitor and respond to climate change.

2.2 Progress with Climate Change at the International Level

The Intergovernmental Panel on Climate Change (IPCC) was set up in 1988 and is a joint organisation of the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO). It is a group of international scientists and policy makers who have been assessing the latest research and implications of climate change. Their second report on climate change in 1995 stated that observations suggest:

> *"a discernible human influence on global climate". This means that climate change is happening and that human activities (especially those that lead to greenhouse gas emissions) are contributing to this.*

The Chairman of the Intergovernmental Panel on Climate Change (IPCC), Robert T Watson, stated in his report to the Fifth Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Bonn, November 1999:

> *"…let me remind you that it is not a question of whether the Earth's climate will change but rather when, where and by how much…"*

Against the background of overall demonstrable climate change, much work is being undertaken to understand the specific "*when, where and how much…*" questions of climate change both at the UK national level and at the sub national/regional level.

In 2001 Working Group I of the IPCC Third Assessment Report (TAR) presented an even stronger case for the link between human influence and climate change. In the Summary for Policymakers' Report of Working Group I of the IPCC (2001a, p19-20), the authors arrived at the following conclusions:

- An increasing body of observations gives a collective picture of a warming world and other changes in the climate system.
- Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate system.
- Confidence in the ability of climate models to project future climate has increased.
- There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.
- Human influences will change atmospheric composition throughout the 21st century.
- Global average temperature and sea level are projected to rise under all IPCC scenarios.

Anthropogenic climate change will persist for many centuries. The TAR also emphasises the importance of understanding the implications of climate change at the regional level. One of the organisations that runs computer models to estimate future climate change at the global level is the UK's Hadley Centre for Climate Prediction and Research. These models are used by the IPCC. The work of the Hadley Centre is briefly described in the next section.

2.3 Progress with Climate Change at the National Level

The UK Climate Impacts Program (UKCIP), set up by the Government in 1997, seeks to develop an integrated approach to impact evaluation in the UK by working with decision-makers. UKCIP provides tools for use in impacts studies, notably the UKCIP climate change scenarios, produced by:

- The Hadley Centre for Climate Prediction and Research, which sits within the Met Office and develops computer models to predict future climate changes based on extensive monitoring and research.
- The Tyndall Centre for Climate Change Research, based at the University of East Anglia, which has a focus on trans-disciplinary climate change research - both mitigation and adaptation - within the context of sustainable development.

The latest UKCIP Climate Change Scenarios report, produced in April 2002, presents a set of four scenarios for future climate change in the UK. These are discussed in Section 4. These scenarios are based on our current understanding of climate change as developed by the Hadley Centre and provide a common starting point for assessing climate change vulnerability, impact and adaptation in the UK.

A number of studies have been, or are being, carried out to interpret the impacts of the scenario climate changes at the regional level. These include studies for Scotland, the North West England, the South East England, Wales, East Midlands, West Midlands, Northern Ireland, Yorkshire and Humber as well as a major conference on climate change impacts in South West England. This London scoping study follows on from the other regional studies under the umbrella of the UKCIP. Studies are also being carried out into sectors that could be vulnerable to climate change such as biodiversity, natural resources (the MONARCH study), health, gardens, water demand, built environment and the marine environment. These studies have been reviewed and information from them, where relevant, has been used in this technical report.

3. Baseline Climate and Environment

3.1 Introduction

The south-east of England enjoys a near continental climate that is most pronounced in the Thames Valley. The region is relatively sheltered from the influence of mid-latitude depressions and, as a consequence, is one of the driest and sunniest parts of mainland Britain. Around the Thames estuary annual rainfall totals average just 500 mm, compared with 600-650 mm across the Thames Valley, and over 1000 mm on the South Downs (Mayes, 1997).

Unfortunately, the climate of London also favours the development of photochemical smog arising from the production of ozone in the presence of pollutants from vehicles and the catalysing effect of sunshine. Extensive urban and suburban landscapes mean that under light winds and little cloud cover, a heat island may develop too, further aggravating local heat stress (Oke, 1987). This is because the urban fabric changes the energy and radiation balance, hydrology and airflow characteristics relative to rural and suburban sites.

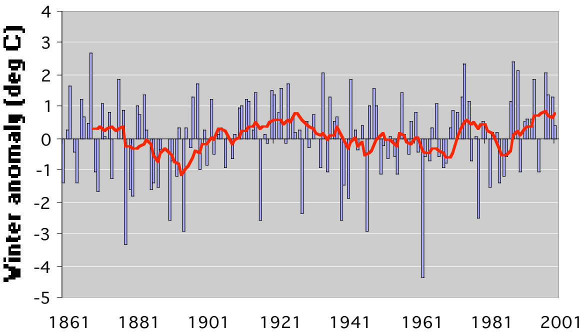
The relatively small area and general paucity of homogeneous climate records for central London, coupled with the artificial heat island, complicates the task of climate change detection and attribution for this urban locale. Where possible, composite records have been employed and/or artificial influences accounted for. However, the importance of recognising data inconsistencies when searching for climate related trends can not be over-stated (Davis, 2000). Regression approaches to trend analysis have also been avoided as the linear form is not necessarily the most appropriate, and because resulting trends can depend on the sub-period of data used.

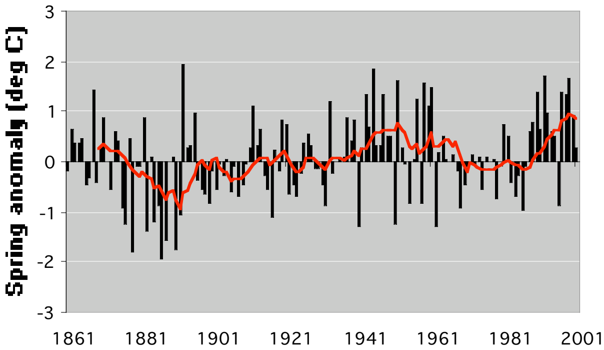
With these issues in mind, the available evidence has been organised in two parts: Sections 3.2 to 3.5 describe the most important changes in driving climate variables, whilst Sections 3.6 to 3.11 describe contemporaneous changes in selected environmental indices. This information provides the baseline for subsequent discussions of regional climate change scenarios and associated impacts. The section concludes with a summary of the key issues and trends.

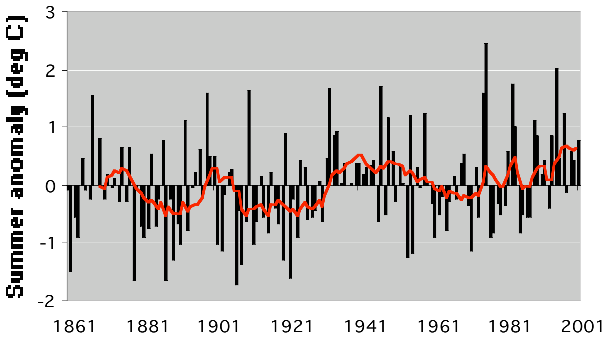
3.2 Temperature

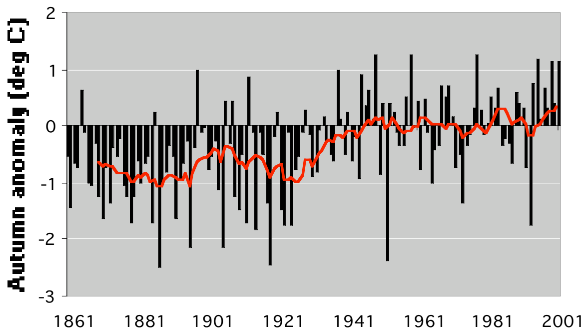
The Central England Temperature (CET) series is the longest instrumental climate record in the world. The monthly catalogue extends back to 1659 and provides a unique insight to climate variability in the UK (Manley, 1953; 1974; Parker et al., 1992). Although the CET record describes temperature changes in the Midlands it is indicative of the signal of temperature change over the Thames Region, and is also untarnished by urban heat island effects. Figure 3.1a shows the record of winter (December to February), spring (March to May), summer (June to August) and autumn (September to November) mean temperature anomalies for the CET from 1861 to 2001. During the 20th Century annual mean temperatures showed a warming of +0.6ºC, with six of the warmest years in the 20th Century occurring since 1989: 1999, 1990, 1997, 1995, 1989 and 1998. Relative to 1961-90 all these years were between 0.9 and 1.2ºC warmer than average. The years 1994 and 2000 were also unusually warm with anomalies close to +0.8ºC. Within the year, warming has been greatest from mid-summer to late autumn: July (+ 0.8ºC), August (+ 1.2ºC), September (+0.9ºC), October (+ 1.2ºC) and November (+1.3ºC) respectively.

Figure 3.1a Central England Temperature record for the post-industrial period, 1861-2001. The anomalies (or departures from the mean) are relative to the 1961-1990 average.



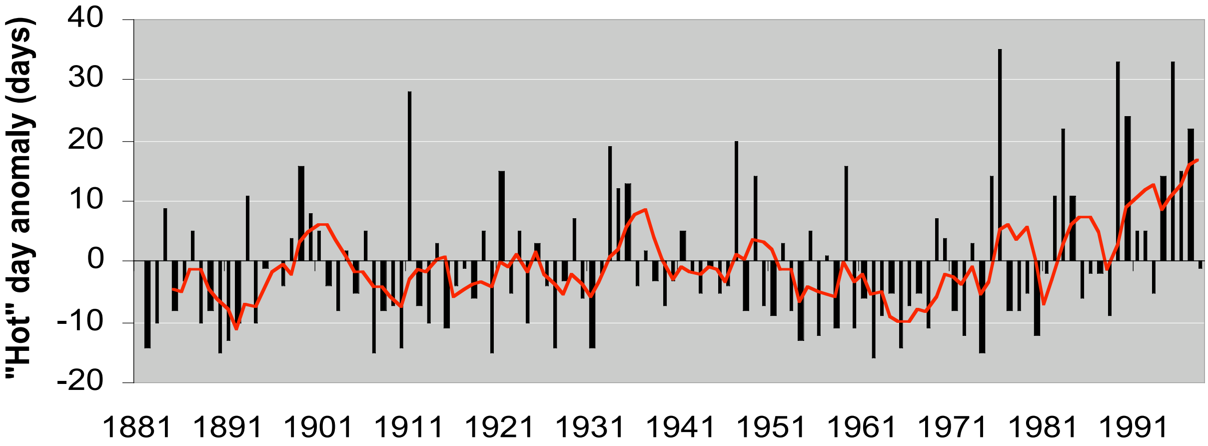






The daily CET has been used to investigate the annual frequency of days classified as 'hot' (mean temperature above 20ºC) or 'cold' (mean below 0ºC) since 1772 (Hulme and Jenkins, 1998). Since the 18th Century, the number of cold days has fallen from around 15-20 per year to around 10 per year presently. Most of this change occurred prior to the 20th Century and is, therefore, probably unrelated to human influences on climate. At the same time, there has been an imperceptible rise in the frequency of hot days in the 20th Century, despite 1976, 1983, 1995 and 1997 returning some of the highest frequencies of such days. Daily maximum temperature data for Kew are also suggestive of a greater number of hot days since the 1970's (Figure 3.1b), but the site may well reflect urban heat island effects (see below). The daily CET also indicates that the growing season for plants has increased by about 30 days since 1900 (Mitchell and Hulme, 2002), and that central England presently enjoys longer frost-free spells than at any time during the pre-industrial era (Wilby, 2001).

Figure 3.1b Annual frequency of hot days (daily maximum > 25ºC) at Kew, 1881-1998. Anomalies are relative to the 1961-1990 average.



As noted above, central London can be several degrees warmer than surrounding rural areas due to the urban heat island effect (Lee, 1992). For example, the average peak temperature difference between the British Museum and a rural reference station in Langley Country Park (about 30 km west) was 3ºC over the summer of 1999 (Graves et al., 2001). Increased urban temperatures have an impact on the summer cooling demand in relation to the 'intensity' of the heat island – defined as the peak difference between urban and rural temperatures. Detailed monitoring indicates that the heat island is most pronounced at night, that it weakens with increasing wind speed and distance from central London, and that the location of the thermal maximum shifts with changes in wind direction (Graves et al., 2001). Figure 3.2a shows that the heat island is also highly changeable from one day to the next (as a consequence of variable weather patterns), attaining differences of up to 7ºC between St James's Park and Wisley on some nights. The annual number of nights with intense heat islands (defined herein as greater than 4ºC) has been climbing at a rate of over four days per decade since the late 1950's (Figure 3.2b). The average nocturnal heat island intensity increased at the rate of 0.1ºC per decade over the same period. Conversely, the number of intense day-time heat-islands has declined to about one event per year since the mid 1980's (Figure 3.2c).

Figure 3.2a **Difference in nocturnal minimum (left column) and day-time maximum (right column) daily temperatures between St James's Park (central London) and Wisley (rural Surrey), July to August 1995.**

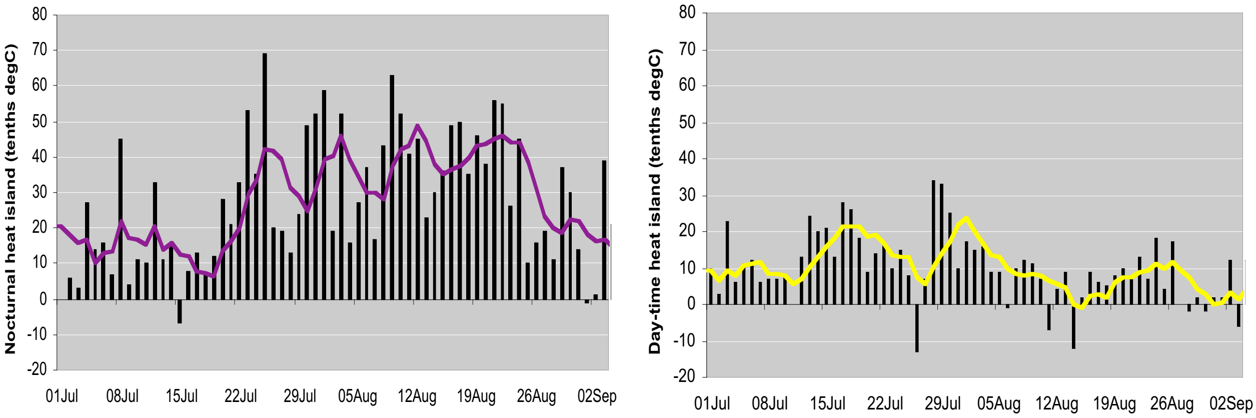


Figure 3.2b **Annual frequency of days with nocturnal heat island intensity greater than 4ºC (left column), and annual average nocturnal heat island intensity (right column) between St James's Park (central London) and Wisley (rural Surrey), 1959-1998. Note: data for November-December 1998 are missing.**

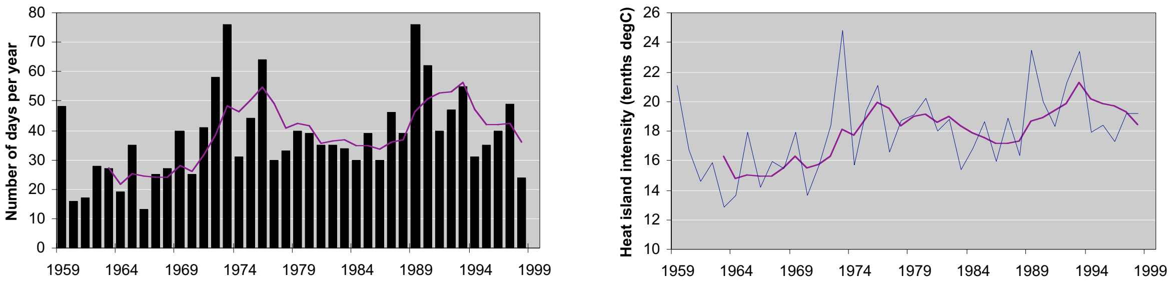
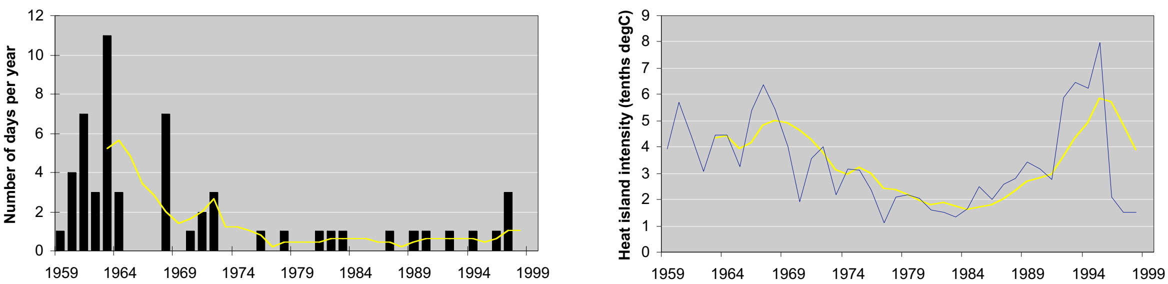


Figure 3.2c **As in Figure 3.2b, but for day-time maximum temperatures**

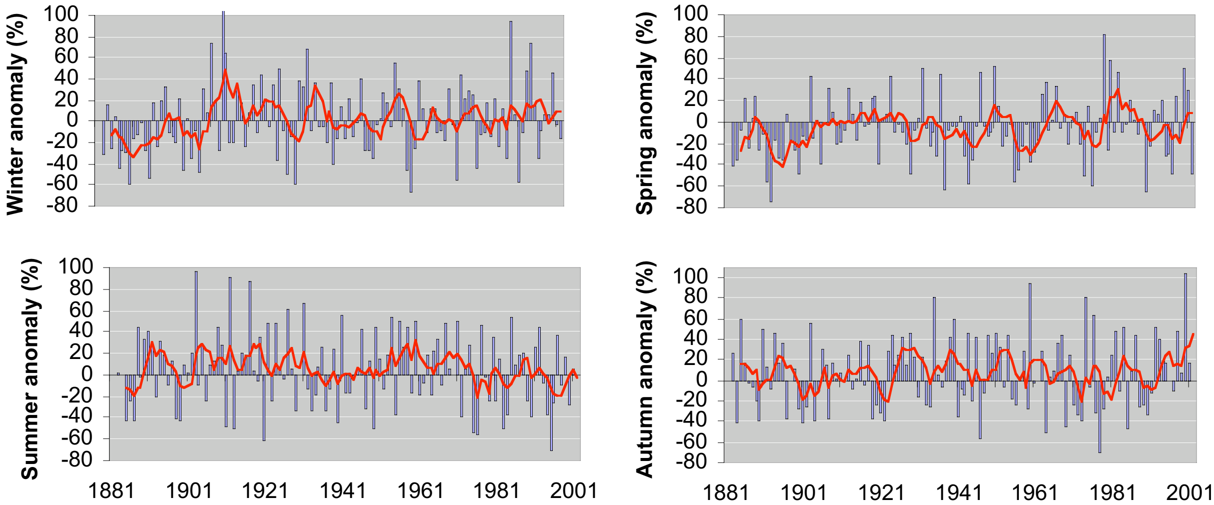


3.3 Precipitation (including snowfall)

Individual precipitation records are particularly susceptible to local conditions, instrumentation and observer practices. The detection of precipitation trends at single stations is also confounded by inter-annual variability (i.e., there is a high level of 'noise' relative to 'signal'). Therefore, recent precipitation trends for the Thames Region were analysed using a composite record of 12 gauges from 1883 (Davis, 2000). This data set also better reflects the Thames-wide water resource context of London.

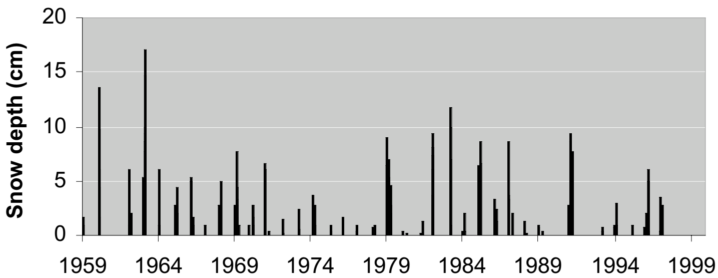
Annual water year precipitation totals (October through following September) for the Thames region indicate a slight but statistically insignificant increase since the 1880's. However, relative to the 1880's winter precipitation has increased by 11% and summer has declined by 10% over the same period (Figure 3.3). The largest changes in monthly precipitation totals have occurred in January (+28%), April (+27%), September (+36%), and July (-26%), but much of the apparent increase is due to the cluster of dry winters and springs in the first few decades of the record (see Brugge, 1993).

Figure 3.3 River Thames seasonal precipitation totals, 1883-2001



Nonetheless, the summers of 1995 and 1976 were still two of the three driest since the 1880's, with seasonal totals respectively –70% and –56% below the 1961 to 1990 average. The second driest summer on record occurred in 1921 and had an anomaly of –62% (see Table 3.1). Conversely, the wettest winters were 1914/15 (+ 112%), followed by the much celebrated winters of 1989/90 (+94%) and 1994/95 (+73%) (see Marsh and Monkhouse, 1993; Marsh and Turton, 1996). A further feature of recent winters has been the steady decline in snowfalls. Since the 1960's the frequency of snowfall in south east England has fallen from 45 days per decade, to 39 in the 1970's and 1980's, to just 23 in the 1990's (see also Wild et al, 1996; 2000). Average areal snowfall depths across the region have also declined in recent decades (see Figure 3.4).

Figure 3.4 Snowfall depths in southeast England, 1959-1999. The composite was derived from observations at Cambridge, Dover and Oxford.



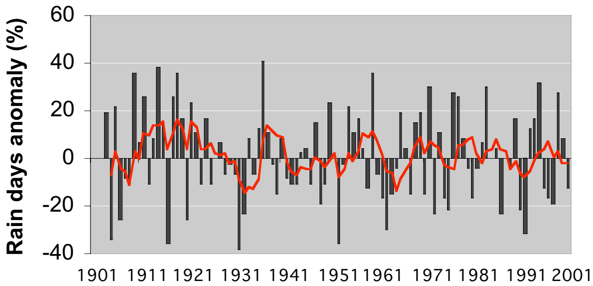
Source: O'Hare and Wild (pers. comm.)

Table 3.1 The five most severe droughts of different duration in the Thames Region defined using the Standard Precipitation Index (from Wade et al., 2001)

Rank	Duration				
	3 months	**6 month**	**12 months**	**24 months**	**48 months**
1	1938	1976	1976	1992	1891
2	1929	1921	1921	1935	1976
3	1893	1929	1922	1934	1901
4	1976	1938	1934	1997	1992
5	1989	1892	1898	1922	1890

Changes in daily precipitation occurrence and wet-day amounts are also relevant to many environmental processes. Since the 1900's there has been no trend in either the frequency of winter rain days or the average length of wet-spells, or persistence of rainfall in the Thames Region (Figure 3.5a). The observed inter-annual variability is consistent with large-scale, atmospheric circulation changes over the North Atlantic (Wilby et al., 1997). Similarly, neither summer rainfall frequencies nor dry-spell persistence exhibit clear trends since the 1900's (Figure 3.5b). However, the 1980's witnessed above average numbers of summer rain days, whilst dry-spell persistence has increased slightly since the 1960's. This suggests that the downward trend in summer rainfall totals (Figure 3.3) is partly driven by fewer rain days.

Figure 3.5a **River Thames winter rain day frequencies and wet-spell persistence, 1904-2001. Anomalies are relative to 1961-1990 average. A wet-day is defined as >0.3 mm/day.**



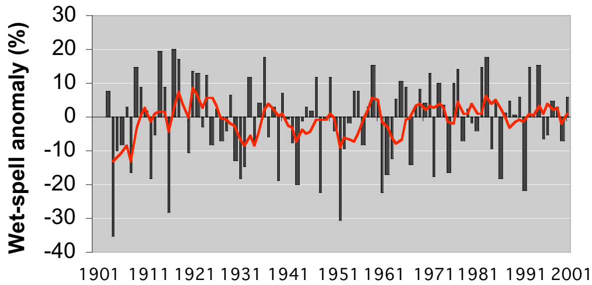
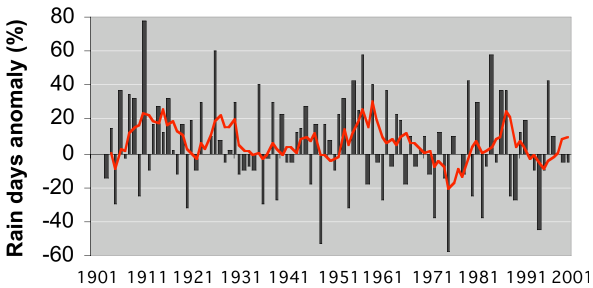
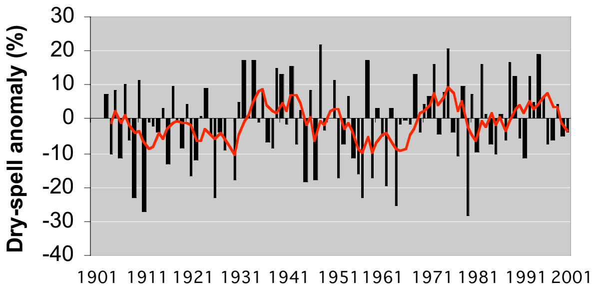


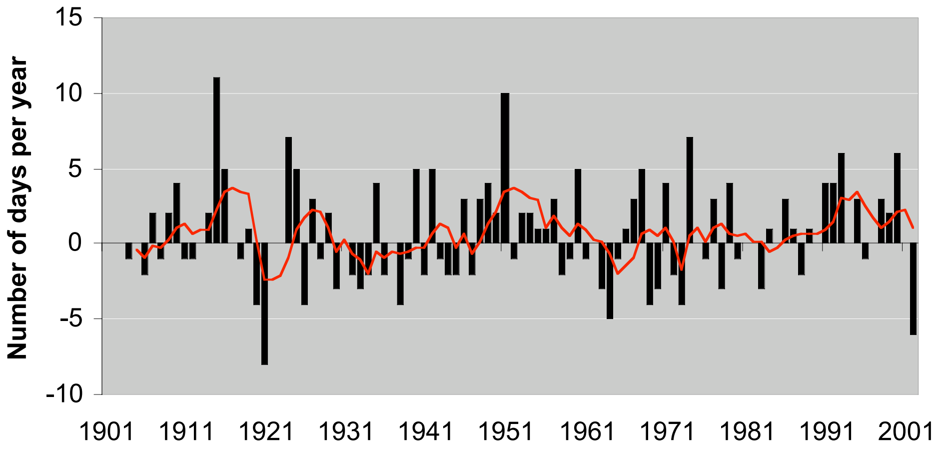
Figure 3.5b **River Thames summer rain day frequencies and dry-spell persistence, 1904-2001. Anomalies are relative to 1961-1990 average. A wet-day is defined as >0.3 mm/day.**





The variability in Thames rainfall should be viewed alongside other studies showing that heavy rainfall events have contributed proportionately more to winter, spring and autumn precipitation totals than light or intermediate storms since the 1960's (Osborne et al., 2000). Conversely, summer rainfall totals have been increasingly dominated by light and moderate precipitation events, leading to a slight reduction in mean intensities during this season.

Figure 3.6 Number of days with precipitation above 12.5 mm/d across the Thames Region, 1904-2001. Anomalies are relative to 1961-1990 average.



The frequency and seasonality of heavy rainfall events contributes to riverine flooding and the exceedence of sewerage capacity. Figure 3.6 shows no consistent trend in the number of heavy rainfall events (over 12.5 mm in a day averaged across the Thames Region – an event that on average occurs 9 times per year). Even when broken down to individual seasons, only autumn shows a small but statistically insignificant increase in such events, amounting to less than one extra day per century.

3.4 Gales

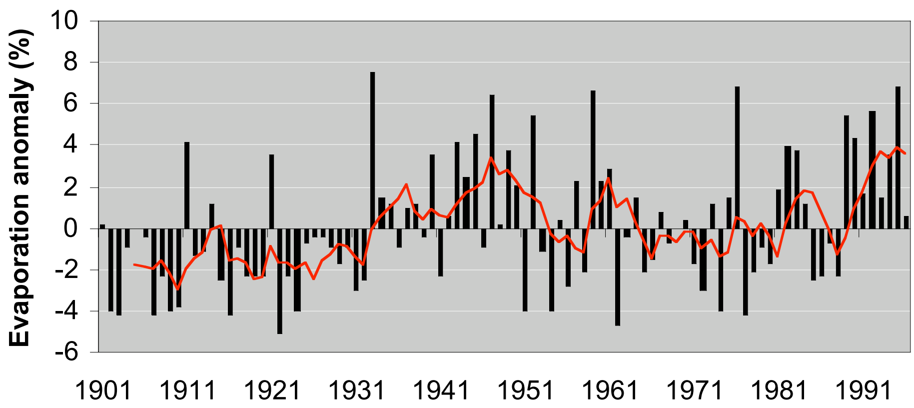
On 16 October 1987 the south east was struck by arguably the most severe storm since 1703 resulting in several fatalities, widespread loss of electrical power, and destruction of woodland (Burt and Mansfield, 1988). However, record wind speeds of 1987 at Kew Gardens (59 knots), were soon surpassed during the storm of 25 January 1990 (71 knots) which struck during daylight hours, leading to severe traffic disruption in London. Despite their significance to infrastructure, long homogeneous records of gale activity are difficult to develop. Nonetheless, Jones et al. (1999) used adjusted grid–point mean–sea–level pressure data to calculate a simple index of gale activity over the UK for the period 1881–1997. This record shows no long–term trend, but the average frequency of severe gales did attain a maximum in the 1990's (corresponding to the pronounced westerly phase of the North Atlantic Oscillation during that decade).

3.5 Potential Evaporation and Relative Humidity

Changes in actual and potential evaporation (PE) have implications for effective rainfall volumes, soil moisture and water resources. However, accurate, long term estimates of these water balance terms are seldom available because of station closures, changes in instrumentation and data inconsistencies. A thorough review of potential evaporation (PE) data was recently undertaken for the Thames Region (Davis, 2000). This analysis concluded that there have been significant increases in PE (Penman method) at Kew since 1871, and for PE (Thornthwaite method) using CETs since 1659. The strongest trends exist in spring and autumn, although all seasons and annual totals show significant increases (Figure 3.7), consistent with observed temperature rises. Indeed, annual PE totals in southern England often exceeded 700 mm in the 1990's – values more typical of western France (Marsh, 2001a).

In contrast, summer relative humidity has generally declined since the 1920's, with exceptionally low humidity values in August during the last two decades (Carter and Robertson, 1998). The Cranwell–Waddington relative humidity series indicates that occurrences of low humidities are becoming more frequent but not necessarily more intense (Lockwood, 2000). However, exceptionally low summer humidities in 1933/34, 1975/76 and 1989/90 were all connected with widespread regional drought.

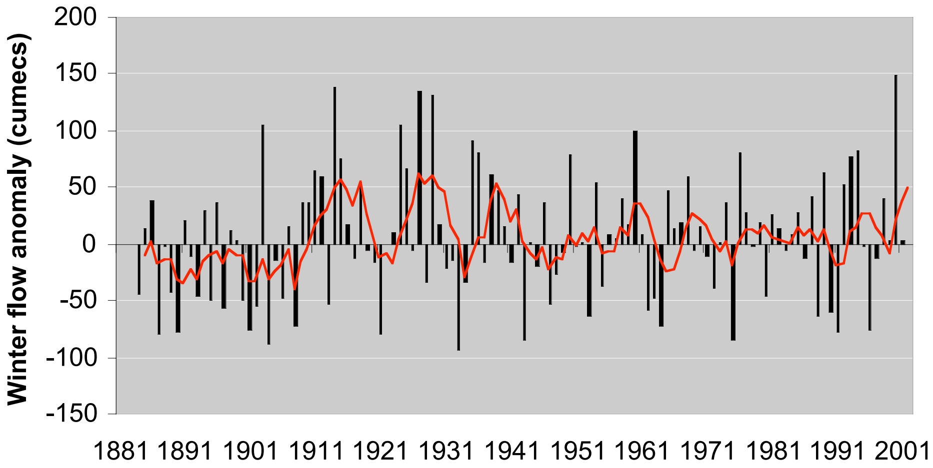
Figure 3.7 Oxford annual potential evaporation anomaly estimated using a modified Thornthwaite method, 1901-1996. Anomalies are relative to 1961-1990 average.



3.6 River Flows

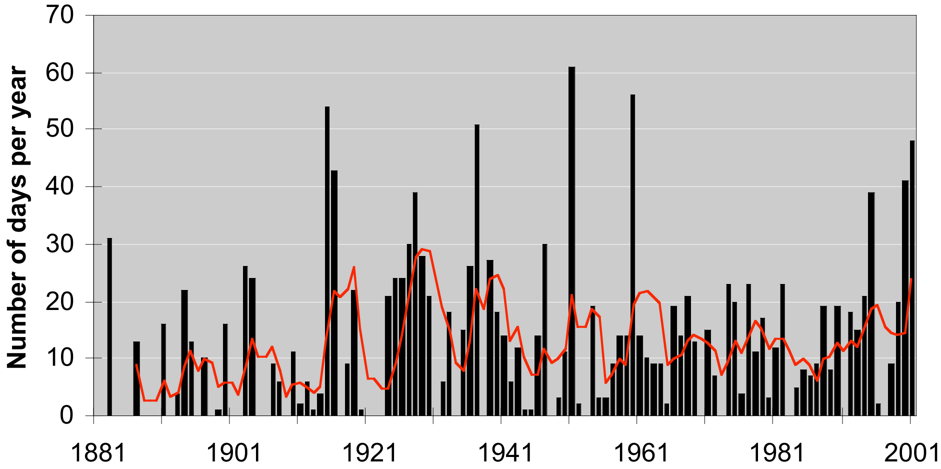
The detection of trends in river flow series is highly problematic because most hydrological records tend to be short (<30 years duration), river flows are typically highly variable from year to year, land-use changes may amplify or conceal climate change signals, and flow regulation, surface and groundwater abstraction mean that the flow regimes of most rivers are dominated by artificial influences (Littlewood and Marsh, 1996; McCabe and Wolock, 1997). Following an analysis of river flows from 29 gauging stations in the Thames Region it was concluded that none have any significant climatically induced trends in terms of water year average flows over the period of record (Davis, 2000). Where trends were detected, they could be explained in terms of water imports, urbanisation or changes in gauging structures. With these caveats in mind, Figure 3.8 shows winter and summer flow anomalies in the naturalised record for the non-tidal Thames at Teddington since the 1880's. Although there are no discernible trends in either series, clusters of summers with below average flow are clearly evident in the 1890's, 1900’s, 1940’s, 1970’s and 1990’s. Conversely, the winter of 2000/01 had the highest 90-day river flow volume on record.

Figure 3.8 River Thames flow anomalies at Teddington in winter and summer (naturalised), 1883-2002. Anomalies are relative to 1961-1990 average.



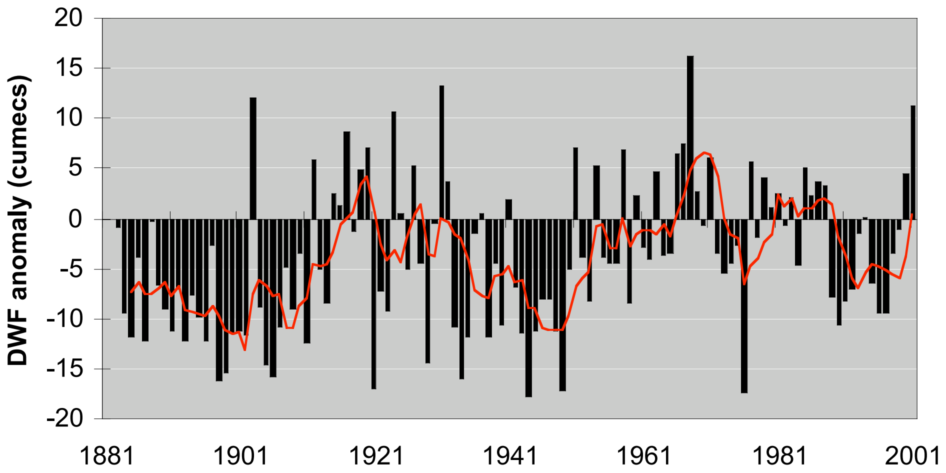
Daily data for Teddington provide an indication of the changing pattern of high flows on the Thames (defined herein as mean daily flows exceeding 250 cubic metres per second, or cumecs). Although the last 30-50 years show strong evidence of increases in the number of high flows, this period is not particularly unusual in the context of the entire record – there have been flow rich periods in the past, most notably the 1920's (Figure 3.9). This is consistent with the national picture of no clear long-term trend in flood peaks, flood volumes or duration of flood flows (Marsh, 2001a, b; Robson et al., 1998). However, the flows of October to December 2000 were the most extreme in terms of England and Wales 90-days totals (CEH and Meteorological Office, 2001). In London two hundred households in Woodford, 75 in Edmonton and Wanstead were flooded (ABI, 2002). In terms of the maximum recorded mean daily flows at Teddington since 1900, the snowmelt event of 1947 was the highest on record (714 cumecs), with the maximum flow of 2000 (464 cumecs) ranked just 50th. The longest duration of flows above 250 cumecs occurred in the winter of 1951 following the wettest February on record (+174% of the 1961-1990 average).

Figure 3.9 Days with River Thames flow at Teddington exceeding 250 cumecs (naturalised), 1883-2002. Anomalies are relative to 1961-1990 average.



There is no single definition of hydrological drought (Mawdsley et al., 1994), however, the annual series of seven-day minimum dry weather flows (DWF) is widely employed. Figure 3.10 shows the DWF for the Thames since the 1880's. The most prominent era of low flows occurred between the 1880's and early 1900's, followed by notable droughts in 1921/22, 1933/34, 1943/44, 1975/76, 1988-92 and 1995-97 (see also Jones and Lister, 1998). Using this index of drought, 1976 is ranked 2nd and 1995 as 50th in the entire record. Although the DWF has declined since the late 1960's there is, again, no clear trend in the overall series for the Thames.

Figure 3.10 Seven-day Dry Weather Flow (DWF) of the River Thames at Teddington (naturalised), 1883-2001. Anomalies are relative to 1961-1990 average.



Note: unmeasured leakage at the Teddington complex prior to 1951 is known to have caused an underestimation of drought flows (Marsh, 2001a).

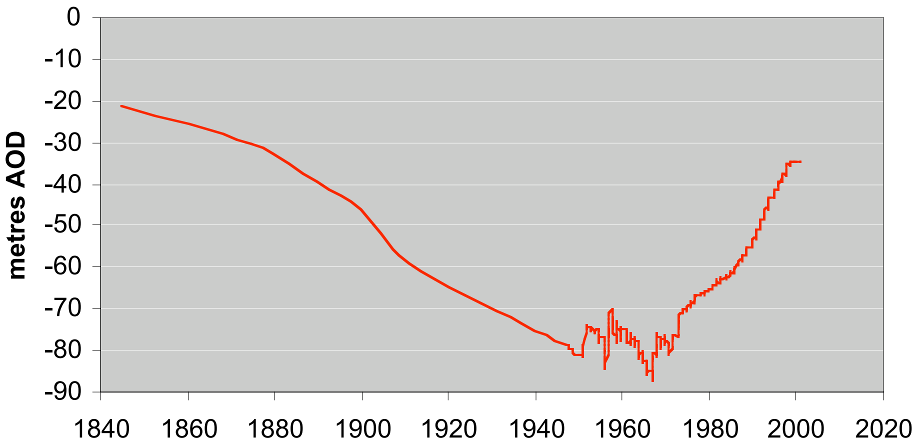
3.7 Groundwater

London is located at the eastern side of the London Basin Syncline, the most extensive chalk aquifer in Britain. For nearly two centuries groundwater has been abstracted from the aquifer mainly for commercial and industrial uses. Groundwater is an essential source of high quality water accounting for 40% of public supply in the Thames Region. Groundwater discharges also contribute to the health of many rivers in the upper catchment (EA, 2001a). Past abstractions resulted in a progressive dewatering of the aquifer under London, and a fall in groundwater levels to a minimum in the 1940's and 1950's (Figure 3.11).

Thereafter, reduced abstractions lead to a reversal of this trend, such that water levels are now rising at up to 2.5 m per year, threatening tunnels and building foundations in central London (EA, 2001b). The General Aquifer Research Development and Investigation Team (GARDIT) is an informal group of interested parties derived from its three original members, Thames Water, London Underground Ltd and the Environment Agency. This group was set up to address the rising groundwater problem. One of the proposals of the GARDIT group was controlling the rise by pumping which could yield an additional source of 30-50 Ml/d water to supply (EA, 2001c).

Conversely, the chalk aquifer to the north east of the Thames Region has been adversely affected by groundwater abstraction at unsustainable levels and by periods of prolonged dry weather (EA, 2001a). Long-term records at the Cholgrove House borehole in West Sussex and at Therfield in Hertfordshire (where artificial influences are minimal), in contrast, are characterised by remarkable stability throughout the 19th and 20th Centuries (Marsh, 2001a).

Figure 3.11 Groundwater levels at Trafalgar Square, 1845-2001

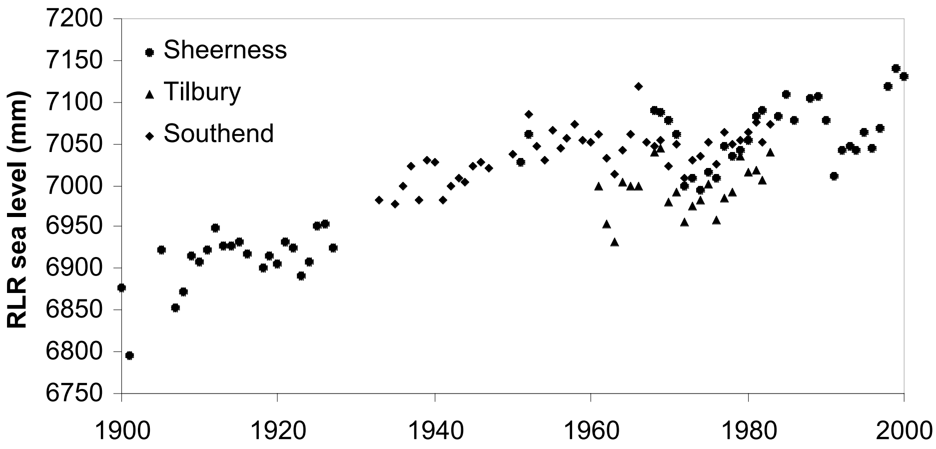


Potable groundwater resources may be impacted adversely by a range of residues originating from agriculture, landfill or accidental spills. Concentrations of nitrates, phosphates and total organic carbon are generally low in the London chalk aquifer due to the clay cover protection from surface pollutants. However, localised contamination by solvents and hydrocarbons has occurred via existing boreholes and other conduits. Shallow groundwater has also been contaminated by urban waste within the gravels aquifer (EA, 2001b).

3.8 Tidal Levels

An anticipated consequence of global warming is a rise in mean sea-level, due to the thermal expansion of ocean water and the melting of land glaciers (Woodworth et al., 1999; Shennan, 1993). Since 1933, the Permanent Service for Mean Sea Level (PMSL) has been responsible for the collection, archiving, and analysis of sea level data from a global network of tide gauges (Woodworth, 1991). This data set currently holds records for over 50 stations around the British Isles, of which about a dozen have records that are at least 30 years in length.

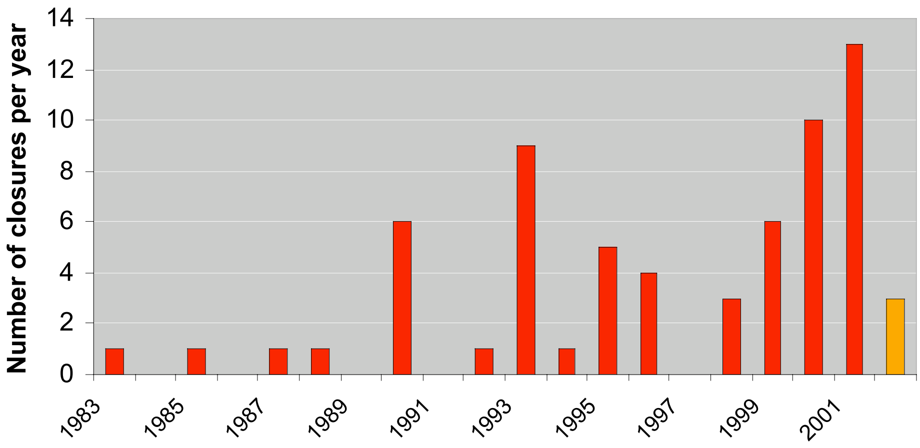
Figure 3.12 Annual mean sea level at Sheerness, Southend and Tilbury, 1901-1999.



Note: in order to construct time series of sea level measurements at each station, the monthly and annual means have to be reduced to a common datum: the 'REVISED LOCAL REFERENCE' (or 'RLR'). This reduction is performed by the PSMSL making use of the tide gauge datum history provided by the supplying authority. The RLR datum at each station is defined to be approximately 7000mm below mean sea level, with this arbitrary choice made many years ago in order to avoid negative numbers in the resulting RLR monthly and annual mean values (see: http://www.pol.ac.uk/psmsl/datainfo/psmsl.hel).

The closest tide gauges to London are at Tilbury, Southend and Sheerness. Figure 3.12 shows the annual mean sea-level at these station since 1901. The combined effects of tectonic subsidence and thermal expansion of the ocean has resulted in an average change in sea-level of +1.44 mm/year. Rising sea levels combined with increased storminess and changes in wave direction and energy, tectonic subsidence and settlement of London on its bed of clay mean that high tide levels in London are rising by about 60 cm per century (EA, 2001b). The Thames Barrier, upstream sea walls, and 32 km of embankments downstream were designed to provide a 1 in 1000 year level of protection to 2030 for London and surrounding areas. Between 1983 and 2001 the Thames Barrier was closed 62 times to protect London from tidal flooding (Figure 3.13). Although the frequency of closure rose steadily during this period(since construction), care should be taken in interpreting this trend, since it is not a long period of record to assess data. The prolonged high river flows of winter 2000/01 resulted in a higher number of closures, since fluvial flow is one parameter by which the need for closure is determined. At present however, it is difficult to determine long term trends based on operating conditions.

Figure 3.13 Number of Thames Barrier closures against tidal surges, 1983-2001

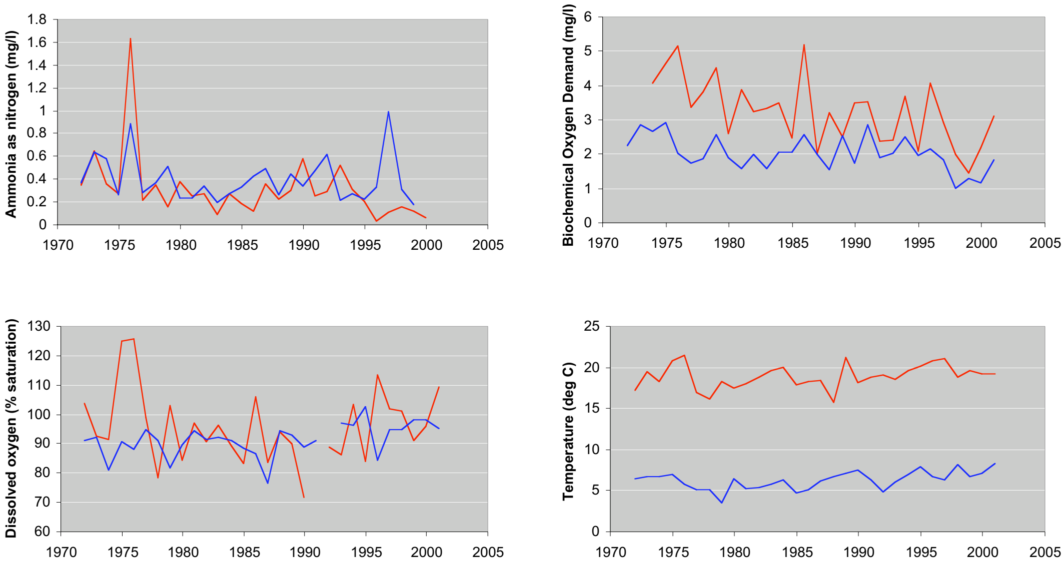


Note: data for 2002 is up to and including 27 April 2002

3.9 Surface Water Quality

The River Thames is now regarded as one of the cleanest metropolitan rivers in the world (EA, 2001b). However, the chemical and biological quality of the London's rivers and estuary is variable due to factors such as changing river flows and urban runoff. The General Quality Assessment (GQA) scheme is used to monitor and assess water quality trends over time and to compare rivers in different areas. The chemical markers of the GQA are defined by standards of dissolved oxygen, biochemical oxygen demand and total ammonia. Overall chemical river quality showed a marked improvement between 1990 and 1995 as flows recovered from the 1989-91 drought, but between 1995 and 1997 quality deteriorated once again as a consequence of the low flows of the 1995 drought (see Figure 3.14). Summary GQA chemical quality data for Thames region shows further improvements in quality for the region's rivers with approximately 60% of monitoring sites showing improvements in water quality from 1990 to 2001 (www.environment-agency.gov.uk) In line with national trends, river water temperatures in the Thames have risen since the 1970's. Rising river water temperatures, particularly in low elevation and slow moving lengths (Webb, 1996) have also been linked to apparent declines in some fish populations and changes in macrophyte communities. For example, at the end of July 2000 extensive algal blooms were recorded between Tower Bridge and Putney.

Figure 3.14 River water quality trends at Teddington in summer (red) and winter (blue), 1972-2001



The GQA scheme for biological quality was introduced in 1995, and monitoring has since shown that the highest quality is found in headwaters, and lowest directly below sewage treatment works outfalls (EA, 2001b). Since 1989, the Agency has used invertebrates and dissolved oxygen as key indicators of chemical water quality of the tidal Thames (and Estuary). Following summer rainfall events, river oxygen levels in the upper and middle reaches of the tideway are severely depleted by increased bacterial activity as organic matter in storm runoff is broken down. As a result of several major fish mortalities between 1973 and 1986, the Thames Bubbler and Thames Vitality have been injecting up to 30 tonnes of oxygen each day at critical locations in the river. Between 1999 and 2000 the vessels were deployed on 55 days, compared with 24 days over the preceding three years. The recent increased usage reflects a combination of higher rainfall and accompanying storm runoff. The organic load discharged during severe storms will, however, be reduced by scheduled improvements to Hammersmith, Western, Lots Road and Abbey Mills pumping stations and at Putney Bridge by 2005 (EA, 2001a). Thames Water's Thames Tideway Strategic Study is currently assessing the environmental impact of storm sewage discharges to the tideway and is also considering what improvements (and associated costs) may be desirable with a view to developing technical solutions. This study recognises that climate change predictions for more frequent storms could, inevitable aggravate water quality problems.

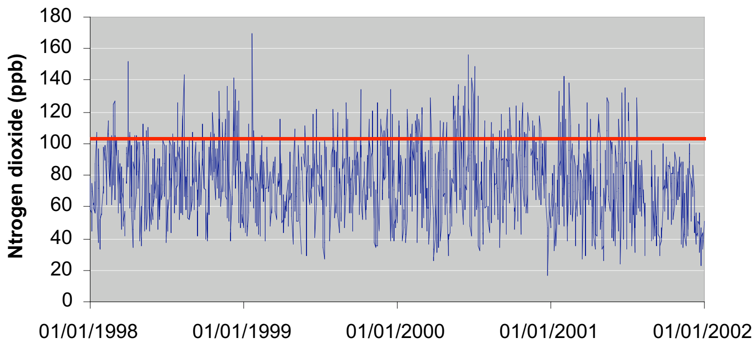
3.10 Air Quality

The Government's National Air Quality Standards (NAQS) represent defined levels of air quality which avoid significant risks to health for eight pollutants (benzene, 1,3-butadiene, carbon monoxide, lead, nitrogen dioxide, ozone, particulates (PM_{10}), and sulphur dioxide). Air quality is monitored by the National Automated Monitoring Networks and Non-automatic Networks at over 1500 sites across the UK, with data available as far back as 1972 for some sites. The reliable detection of air quality trends is complicated by the brevity of data sets, changes in instrumentation, representativeness of monitoring sites and the strong control exerted by weather patterns on pollution episodes (Crabbe et al., 1999; McGregor and Bamzelis, 1995; Scaperdas and Colvile, 1999; Comrie, 1992).

According to the Sustainable Development Unit, DEFRA, there has been a decline in the number of days nationally when air pollution was classified as moderate or high at urban sites from an average of 59 days per site in 1993, to 21 days in 2001. However, air quality remains at unacceptable levels in many parts of London. For example, in Marylebone particulate concentrations exceeded NAQS on over 30 days in 1998 and 1999 (EA, 2001b). Furthermore, a positive correlation has been shown between air pollution and social deprivation in London, with higher concentrations of nitrogen dioxide and particulates found in areas exhibiting higher social deprivation (Pye et al., 2001).

Traffic emissions of nitrogen dioxide and particulates have replaced sulphur dioxide from coal-burning as the most significant air quality problems currently facing London (Eagleson et al., 1992). The highest concentrations of nitrogen dioxide are found in central London (Figure 3.15) and along busy road corridors. Background concentrations of particulates are highest in the east of the Thames Region due to secondary particles, such as sulphate and nitrate formed from chemical reactions in the atmosphere, that originate from mainland Europe. Concentrations of sulphur dioxide are also highest in the East Thames Corridor due to emissions from a number of power stations and a refinery (EA, 2001b). Maximum concentrations of ozone, however, tend to occur at weekends outside of central London due to transportation by wind (Wilby & Tomlinson, 2000), as well as lower concentrations of ozone destroying pollutants (principally nitric oxide) in rural areas. Peak ozone concentrations in central London typically occur under stable summer anticyclonic weather which favours photochemical action (O'Hare & Wilby, 1994).

Figure 3.15 Daily maximum hourly average nitrogen dioxide concentrations (ppb) kerbside at Marylebone Road, 1998-2001. Note: the National Air Quality Standard for nitrogen dioxide is 105 ppb for a one hour mean. This limit should not be exceeded more than 18 times per year.



Data source: National Environmental Technology Centre

3.11 Biodiversity

The word biodiversity has figured prominently in discussions of the environment since the Earth Summit at Rio de Janeiro in 1992, when over 150 countries adopted a Biodiversity Convention. In the present context biodiversity is taken to mean the whole variety of life supported by the wildlife habitats of London. As Table 3.2 indicates, the City contains a number of nationally and internationally important habitats, species of plants and animals. Despite the City's urban character, nature conservation designations apply to 16% of its area, covering a range of habitats including wetlands, woodland, water bodies, heathland, urban wasteland, marshes, and mudflats (Table 3.3). The gardens and parks of London also have an important role in the conservation of wildlife species, not least for their part in the Green Corridor network of the Mayor's Biodiversity Strategy (2002). It is hoped that this network of waterways, canals and railsides will allow some species with specialised habitat requirements to extend their distribution across the City. London is also home to important populations of several nationally rare plants and animals including the stag beetle, greater yellow-rattle, black redstart, burrowing bee and wasp, serotine and noctule bats, the kingfisher, and rare species of fish such as smelt, sea lamprey and the protected twaite shad.

Obvious threats to biodiversity include the degradation and/or loss of wildlife habitats, the introduction and spread of problem species that threaten other wildlife, water pollution, unsympathetic management, and encroachment of inappropriate development (Table 3.4). The recent declines of wildlife species, such as the house sparrow and starling, however, are much harder to explain (Robinson et al., 2001; RSPB, 2000). In addition, many terrestrial and aquatic species are sensitive to the direct effects of climate variability, and/or indirectly through changes in related environmental processes such as river flow (Cannell et al., 1999). For example, several species have recently colonised south-east England or expanded their distribution northward (e.g., the Lesser Emperor dragonfly, Roesel's Bush Cricket, and the Little Egret). Conversely, the salmon population of the Thames suffered a dramatic decline from the peak in 1993 — at least partially due to the recent dry summers and their effect on river flows — but has been making a gradual recovery since 1998 (EA, 2001b). Changes in river flow regimes can, in turn, affect the thermal and chemical quality of waters, on in stream habitat availability, salinity, and on rates/patterns of fluvial and estuarine deposition (e.g., Owens and Walling, 2002; Webb, 1996). Alterations to river flows, substrates, salinity or tidal exposure also have the potential to modify invertebrate communities (Wood et al., 2000).

Table 3.2 Nature conservation designations in London

Status	Location(s)	Importance
Special Protection Area under the European Union Birds Directive.	Walthamstow Reservoirs; Kempton Park Reservoirs.	Internationally important populations of waterfowl.
Special Areas of Conservation under the European Union Habitats Directive (pending).	Wimbledon Common, Richmond Park and Epping Forest.	Stag beetle.
Ramsar sites.	Lee Valley and South West London Waterbodies Special Protection Areas.	Wetlands
Important Bird Areas	Walthamstow Reservoirs, Chingford Reservoirs and Walthamstow Marshes; Kempton Park Reservoirs; Rainham and Wennington Marshes	Bird populations
UNESCO World Heritage Sites (nominated)	Kew Gardens; Down House in Bromley Borough	Natural history resource; Charles Darwin’s former home.
Sites of Special Scientific Interest in London (38)	Including Richmond Park and the Inner Thames Marshes; Ruislip Woods and Richmond Park have recently been designated National Nature Reserves.	Ancient woodlands (10), grassland (7), mixed woodland and grassland (3), wetlands (10), heathland and bog (2), parkland (1), and geological interest (5).
Sites of Importance for Nature Conservation	About 140 Metropolitan sites, with a total area of nearly 16,000 Ha (10% of London’s land area).	Important wildlife sites as recognised by the London Borough councils.
Sites of Borough Importance	310 Grade I sites, 460 Grade II sites, with a total area of about 12,000 hectares (almost 8 per cent of London’s land area).	Local importance, providing people with access to nature close to home.
Countryside Conservation Areas	Various	Small fields with good hedgerows, surviving field ponds, copses and green lanes
Green Corridors	Links between sites and to Green belt by rivers, canals and railside land.	Enabling some species to extend their distribution.
Local Nature Reserves (76)	Various	Intrinsic biodiversity value and local importance.

Source: Mayor’s Biodiversity Strategy (2002)

Table 3.3 Selected wildlife habitats in London, their biodiversity significance, associated threats and opportunities

Habitat	Area (Ha)	Location(s)	Importance	Threats	Opportunities
Woodland	7,300	Outer Boroughs such as Bromley; <20 Ha amongst the seven Boroughs along the Thames from Hammersmith/Fulham to Barking/Dagenham.	One of the most diverse habitats; one third classified as ancient; yew, beech and hornbeam; hawfinch, marsh tit, spotted flycatcher; bird's nest orchid, coral-root bittercress.	Threat of clearance; damaged by amenity management and/or public over-use; changes in water regime through drainage or flood control; water and air pollution.	Sympathetic and appropriate woodland planting; promote natural succession to wet woodland at disused mineral workings; pond creation.
Grassland (pasture/meadow) (acidic) (chalk)	 11,000 1,200 300	Frequently mown amenity grass widespread; acid grassland in Richmond; chalk grassland in southern Boroughs such as Croydon, Bromley, and Sutton.	Common birds such as blackbird and mistle thrush; unique invertebrate communities; wild flowers, including orchids.	Agricultural improvement; mowing and drainage of rough grasslands; poor management, over-grazing; fragmentation and isolation of habitat; tree-planting; development.	Relaxation or modification of mowing regimes; uncut areas of perennial grasses; sympathetic grazing regime; harvesting of grass as a crop.
River Thames and tributaries	2400	Within Greater London boundaries; wetland habitats in the catchments of the Colne, Ingrebourne, Cray and Roding.	Supports 118 species of fish; 450 species of invertebrate in tidal zone; significant populations of ringed plover, dunlin and redshank (downstream), grebes, ducks, herons, gulls, cormorants and terns (upstream).	Water pollution by huge organic loads from storm drains during summer storms; accidental oil or chemical spills; disturbance of sensitive riverside species; encroachment by development; reconstruction of river walls.	Habitat restoration and re-creation; creation of shingle beaches and salt marsh; curtailing of dredging; appropriate riverside development and flood defence schemes; environmental education resource.
Ponds, canals and lakes	1,500+	Former farm ponds; canals to the north of Thames; lakes on former country estates; gravel pits and storage reservoirs.	Diverse populations of fish and common dragonflies; great crested and palmate newts; over-wintering wetland birds; kingfisher.	Redevelopment of canalsides; increased disturbance and recreational pressure; desilting and vegetation clearance; water pollution; infilling and nutrient enrichment; operational activities.	Habitat enhancement and creation schemes; integration within Green Corridor network; pond restoration; flooding of former gravel pits; sympathetic management of operational reservoirs.

Habitat	Area (Ha)	Location(s)	Importance	Threats	Opportunities
Heathland	80	Wimbledon Common and Putney Heath, Poor's Field in Hillingdon, Stanmore Common in Harrow, the Addington area of Croydon and Hayes Common in Bromley.	Scarce and declining habitat; dwarf gorse, petty whin, cotton grass; black darter dragonfly, green hairstreak, yellow underwing.	Lack of appropriate management; nutrient enrichment from air pollution; inappropriate tree planting; limited opportunities for expansion.	Heathland restoration and re-creation in suitable areas adjacent to existing habitat; re-instatement of grazing; sympathetic management of patches on golf courses.
Farmland	12,000	Mainly in the Green Belt of the outer London Boroughs	Brown hare and birds such as tree sparrow, skylark, corn bunting and grey partridge.	Agricultural intensification; fertiliser, herbicide and insecticides; neglect of hedgerows and ponds; inappropriate tree-planting; change of land-use to leisure activities.	Set-aside and stewardship schemes; organic farming and reversion to 'traditional' farming methods; biodiversity conservation as part of housing planning.
Marshland	273	Ingrebourne Marshes; Denham Lock wood; Farm Bog; Walthamstow Marsh; The Chase Nature Reserve	Wet terrestrial habitat (bog, swamp, fen, wet marginal vegetation, wet marshy grassland and ditches); important for breeding birds such as sedge warbler, reed warbler, reed bunting; dragonflies; water vole; grass snake; frogs and bats.	Development, water abstraction, pollution, lack of, or inappropriate management; summer droughts and/or hydrological changes through drainage schemes; fragmentation; succession to woodland.	Rehabilitation and restoration under Local Environment Agency Plans (LEAPs); incorporating habitats in new flood defence or surface water drainage schemes; Water Level Management Plans; restoration of former gravel pits.
Parks and squares	~12,500	Royal Parks and smaller local parks e.g. Richmond, Regents, Battersea.	Common birds, butterflies and animals; heronries in park lakes.	Unsympathetic management; piece-meal disposal for development; recreational pressure.	Restoration of relic features and habitats; creation of ponds or wildflower meadows; relaxing mowing regimes; integration within Green Corridor network.
Cemeteries and churchyards	1,300	Victorian cemeteries such as Highgate, Nunhead, Kensal Green and Abney Park	Less intensively managed than parks; uncommon ferns and lichens; relict grassland with rare wild flowers.	Increasing pressure for re-use of burial space; well-ordered 'tidy' appearance.	Reduction of mowing frequency; introduction of bird and bat boxes; promotion of 'green burials'; habitat restoration; educational resource.

Habitat	Area (Ha)	Location(s)	Importance	Threats	Opportunities
Gardens and allotments	31,000	Ubiquitous	Habitats similar to hedgerows or edges of woodlands; garden ponds; breeding linnet and goldfinch on allotments; common birds and butterflies in gardens.	Lack of appreciation of habitat value; cutting hedges during bird breeding season; removal of leaf-litter and dead wood; paving of front-gardens; chemical pesticides; backland development and infilling.	Wild-life friendly gardens; vast and intricate network of green corridors; point of contact with the natural environment.
Railway land, line sides & road sides	1,000+ (Sites of Importance for Nature Conservation)	Examples include Sydenham Hill station and New Cross Gate cutting managed as nature reserves.	Network of a variety of habitats, chiefly woodland, scrub and rough grassland; locally important bird and insect populations.	Habitat loss through development or operational requirements; clear-felling of trees to reduce leaf-litter; herbicide treatments; fly-tipping.	Management guidance taking account of ecology; restoration of grassland habitats and woodland edges; high potential for raising awareness of biodiversity value.
Wasteland	Unknown	Incompatible definitions; but disappearing habitat due to redevelopment.	Rare insects and birds, such as the black redstart; rapid colonisers; invertebrates.	Proposals for redevelopment and/or decontamination; lack of awareness of nature conservation value; existing value assumed less than that of improvements.	Establishment/maintain urban wasteland nature reserves; opportunities to research biodiversity in the built environment; create roof-top urban wastelands; promote natural colonisation by wasteland flora and fauna.

Sources: Mayor’s Biodiversity Strategy (2002) and London Biodiversity Partnership (2002).

Table 3.4 Exemplar biodiversity issues currently facing London

Species/habitat	Trend	Distribution	Key issues
Water Vole	Disappeared from over 72% of sites occupied prior to 1997.	Rainham Marshes, Crayford-Erith Marshes, River Cray, Lee Valley.	Predation by feral American mink; sensitive habitat management.
Noctule and serotine bats	Significant decline since the mid-1980's	Buildings, bridges, trees and underground roosts.	Disturbance, damage or destruction of roosts; loss of insect-rich feeding habitats such as wetlands, woodlands and grasslands; loss of flight line features; artificial lighting.
Reed Bunting	Fluctuation in response to weather.	Rainham Marshes, inner Thames Marshes SSSI, Walthamstow Marshes, Walthamstow Reservoir, Brent Reservoir SSSI.	Deterioration of wetland habitats; intensification of agricultural practices.
Bittern	National decline since 1960's; numbers boosted by continental migrants.	Visitor to London Wetland Centre in 2002, over winters in Lee Valley Park.	Loss and fragmentation of reedbed habitat; small population size; pesticide and heavy metal pollution.
House sparrow	Dramatic decline in recent years across many parts of the United Kingdom.	Completely disappeared from large areas of London where it was common until only a few years ago.	More intensive agriculture has affected most farmland birds, but causes of urban decline are not known.
Black redstart	Currently declining.	Abandoned industrial sites in the east Thames corridor.	Habitat loss through urban regeneration.
Bumblebee	Drastic decline in range in recent decades	Wasteland sites with sandy substrates, open conditions and low nutrient status.	Habitat loss through urban regeneration.
Coastal Salt Marsh	Currently declining.	Tidal Thames.	Development pressures; erosion; over-grazing; tidal defences.
Chinese Mitten Crab	Problem species, increasing unchecked.	River Thames as far as Staines, Rivers Roding, Lee, Darent, Cray, Mole, Crane, Brent, Hogsmill, Wandle, Quaggy, & Ash.	Destruction of natural banks and reed beds; possible predation of the White-clawed Crayfish.
Floating Pennywort	Introduced, problem species, spreading rapidly throughout the waterways and wetlands of Greater London.	River Lee south of M25, Rivers Roding and Wandle, Marsh Dykes, Brent Reservoir SSSI, Wetland Centre at Barnes, Epping Forest.	Out competes other plants forming dense mats; deoxygenates water; restricts flow; hampers navigation, flood control, surface abstraction & recreation.
Salmon	Significant decline between 1993 and 1998, slight recovery since.	River Thames	Excellent indicator of water quality; fish rearing and stocking; construction of fishes passes; recent decline attributed to dry summers and lower flows; If the temperature of the river increases significantly, conditions will become increasingly unsuitable for salmon.

Sources: Environment Agency (2001b), London Biodiversity Partnership (2002), and the Mayor's Biodiversity Strategy (2002).

3.12 Summary

The preceding sections provide a review of the recent trends and changes in key environmental indices. The benchmarks, summarised in Table 3.5, form the basis for subsequent discussions of future climate scenarios and potential environmental impacts facing London.

Table 3.5 Key climate and environmental trends in London and the wider Thames Region

Climate indicators	Recent trend
Air temperature	Annual average has risen by +0.6ºC since 1900's
	Several of the warmest years on record have occurred since 1989
	Most rapid warming in period July to November
	Fewer 'cold' days and longer frost free season
	Growing season +30 days since 1900's
	Nocturnal urban heat island intensifying
Rainfall	Decreasing summer rainfall since 1880's
	Increasing winter rainfall over last 150-200 years
	Two of three driest summers were 1995 (1st), 1976 (3rd)
	Two of three wettest winters were 1989/90 (2nd), 1994/95 (3rd)
	More winter rain days and longer wet-spells since 1960's
	Heavy storms contribute more to winter rainfall totals since 1960's
	Lighter, more frequent summer storms
Snowfall	Fewer snowfall events and smaller snowfalls since 1960's
Gales	Record wind speeds in 1987 and 1990
	No long-term trend but cluster of severe gales in the 1990's
Evaporation and relative humidity	Increases in PE in all seasons but especially spring and autumn
	Decline in summer RH since 1920's
River flow	No discernible trends that may be linked exclusively to climate
	Notable low flows in the 1880's to 1900's, 1940's, 1970's, 1990's
	Flood rich period in the 1920's
	Increases in number of high flows in last 30-50 years
	Winter 2000/01 highest 90-day flow volume in the Teddington record
Groundwater	Levels increasing by up to 2.5 m/yr in central London
	Local declines due to unsustainable abstraction and dry weather

Climate indicators	Recent trend
Tidal levels	High tide levels rising by 6 mm/yr (includes subsidence)
	Frequency of Thames Barrier closure increased during the 1990's
River water quality	Water quality trends reflect fluctuations in rainfall intensity and river flow volume
	Droughts of 1989-91/1995-97 led to deterioration of river quality
	River water temperatures have risen in the Thames
	Combined sewer outflows severely deplete oxygen levels following severe summer storms
Air quality	Air quality is failing standards in many parts of London principally due to traffic emissions
	Key pollutants are nitrogen dioxide, particulates, ozone, and sulphur dioxide
	Weather patterns strongly affect ambient pollution levels
Biodiversity	Decline in some species due to predation, e.g. Water Vole
	Decline in some species due to agricultural intensificaton, e.g. House Sparrow
	Decline in some species due to loss of habitat, e.g. Bumblebee
	Loss of habitats due to redevelopment e.g. marshland and urban wasteland
	Spread of problem species, e.g. Floating Pennywort, Chinese Mitten Crab
	Increasing pressures from recreation and amenity, e.g. woodland, waterways
	Fragile, but generally recovering Salmon population

3.13 Bibliography

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4. Future Climate Scenarios

4.1 Introduction

In 1995 the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report (SAR), concluded that the observed rise in global average temperature over the 20th Century '*is unlikely to be entirely natural in origin*" and that "*the balance of evidence suggests that there is a discernible human influence on global climate*". As state previously in Section 2.2 in 2001 Working Group I of the IPCC Third Assessment Report (TAR) presented an even stronger case for the link between human influence and climate change.

4.2 Global Climate Projections

Climate model projections of future global–mean temperature and sea level change depend on future estimates of greenhouse–gas and sulphate aerosol emissions. In 2000, the IPCC approved a new set of emission scenarios to update and replace the IS92 scenarios used in the IPCC SAR. The new scenarios, presented in the IPCC *Special Report on Emission Scenarios* (SRES), have much lower emissions of sulphur dioxide than the IS92 scenarios. Although the scenarios cover a total of 40 future demographic, economic and technological 'storylines', just four marker scenarios have received most attention within the scientific community (Table 4.1). It is not possible to attach probabilities to any of the SRES scenarios; they are all plausible descriptions of socio–economic trends that could affect future emissions of greenhouse gases.

Table 4.1 SRES storylines used by the IPCC for future greenhouse gas emission scenarios

Scenario	Outline
A1F1	Very rapid economic growth, a global population that peaks in mid–21st Century and thereafter declines, and the rapid introduction of new and efficient technologies. The scenario also envisages increased cultural and social interaction, with a convergence of regional per capita income.
A2	A very heterogeneous world, characterised by self–reliance and preservation of local identities. Population continues to grow but economic growth and technological change are slower than other storylines.
B1	The same population dynamics as A1, but a transition toward service and information economies, with lower material consumption and widespread introduction of clean and efficient technologies.
B2	A world with lower population growth than A2, accompanied by intermediate levels of economic development, with less rapid and more diverse technological change than in B1 and A1.

Table 4.2 summarises the key features of observed and projected climate changes presented in the *Summary for Policymakers' Report* (IPCC, 2001a). Table 4.3 focuses on extreme events and the levels of confidence attached to observed global trends and model projections.

Table 4.2 Consensus about future changes in the climate system

Temperature

- The global average surface temperature has increased by 0.6±0.2ºC since 1861, although most of the warming occurred during two periods, 1910 to 1945 and 1976 to 2000.
- Globally, it is likely that the 1990s was the warmest decade and 1998 the warmest year in the instrumental record, since 1861.
- Proxy data for the Northern Hemisphere indicate that the increase in temperature in the 20th century is likely to have been the largest of any century during the past 1000 years.
- Between 1950 and 1993 night-time daily minimum temperatures over land increased by about 0.2ºC per decade (about twice the rate of increase in daytime daily maximum air temperatures).
- Since 1950 it is very likely that there has been a reduction in the frequency of extreme low temperatures, with a smaller increase in the frequency of extreme high temperatures.
- Globally averaged surface temperature is projected to increase by 1.4 to 5.8ºC over the period 1990 to 2100.

Precipitation

- It is very likely that precipitation has increased by 0.5 to 1% per decade in the 20th century over most mid- and high-latitudes of the Northern Hemisphere continents.
- It is likely that there has been a 2 to 4% increase in the frequency of heavy precipitation events in the latter half of the 20th century over mid- and high-latitudes of the Northern Hemisphere.
- Over the 20th century (1900 to 1995), there were relatively small increases in global land areas experiencing severe drought or severe wetness.
- There has been a 2% increase in cloud cover over mid- to high-latitude land areas during the 20th century.
- Northern Hemisphere snow cover and sea-ice extent area projected to decrease further.
- Global water vapour concentration and precipitation are projected to increase during the 21st century.
- Larger year to year variations in precipitation are very likely over most areas where an increase in mean precipitation is projected.
- No systematic changes in the frequency of tornadoes, thunder days, or hail events are evident in the limited areas analysed.

Sea level

- Tide gauge data show that global average sea level rose between 0.1 and 0.2 metres during the 20th century.
- Global sea level is projected to rise by 0.09 to 0.88 metres between 1990 and 2100, for the full range of SRES scenarios.

Source: IPCC (2001a)

Table 4.3 Estimates of confidence for selected observed and projected changes in extreme weather and climate events

Changes in phenomenon	Confidence* in observed changes (latter half of 20th century)	Confidence* in projected changes (during the 21st century)
Higher maximum temperatures and more hot days over nearly all land areas	Likely	Very likely
Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very likely	Very likely
Reduced diurnal temperature range over most land areas	Very likely	Very likely
Increase of heat index over land areas	Likely, over many areas	Very likely, over most areas
More intense precipitation events	Likely, over many NH land areas	Very likely, over many areas
Increased summer continental drying and associated risk of drought	Likely, in a few areas	Likely, over most mid-latitude continental interiors

* IPCC qualitative classification of confidence levels: Likely (66 to 90%), Very likely (90 to 99%)
Source: IPCC (2001a)

4.3 Climate Change Scenarios for the UK and London

Since the publication of the UKCIP98 scenarios (Hulme and Jenkins, 1998), significant advances in computing power have enabled a greater number of climate model experiments to be conducted at higher spatial resolutions. The Hadley Centre global climate model (HadCM3) was used to drive a high resolution atmospheric model (HadAM3H) and, in turn, a regional climate model (HadRM3) for Europe. These experiments resulted in the development of the UKCIP02 scenarios (Hulme et al., 2002) which describe how the climate of the UK land area may change in the 21st Century at a resolution of ~50 km (as opposed to the ~300 km resolution of UKCIP98). The new scenarios also provide more information about changes in extremes of weather and sea level, and are explicitly linked to the four SRES storylines described in Table 2.1 (B1~**Low Emissions**, B2~**Medium-Low Emissions**, A2~**Medium-High Emissions**, A1F1~**High Emissions**). In contrast, the UKCIP98 scenarios were based on much simpler descriptions of future population and fossil fuel use.

Table 4.4 Summary of results presented in the UKCIP02 Scientific Report

- The UK climate will become warmer by between 1 to 2ºC by the 2050 and by up to 3.5ºC by the 2080's, with parts of the south-east warming by as much as 5ºC in summer.
- Higher summer temperatures will become more frequent and very cold winters will become increasingly rare.
- Winters will become wetter and summers may become drier everywhere.
- Summer soil moisture may be reduced by 40% or more over large parts of England by the 2080s.
- Daily maximum temperatures of 33ºC, which occur about 1 day per summer in the south-east, could occur 10 days per summer by the 2080's.
- Snowfall amounts will decrease throughout the UK.
- Heavy winter precipitation (rain and snow) will become more frequent.
- Relative sea level will continue to rise around most of the UK's shoreline.
- Extreme sea levels will be experienced more frequently.
- The Gulf Stream may weaken in the future, but it is unlikely that this weakening would lead to a cooling of UK climate within the next 100 years.
- In central London the urban heat island effect could add a further 5 to 6ºC to temperatures during summer nights.

Source: Hulme et al., 2002

Despite these advances, the UKCIP98 and UKCIP02 scenarios (Table 4.4) are qualitatively very similar. The main differences in UKCIP02 are: a) slightly higher warming rates over the UK; b) smaller rates of sea level rise; c) summers are now projected to become drier over the *whole* UK, and by a larger amount; d) changes in the patterns of average wind speed; e) less marked increase in the frequency of heavy rainfall days. Tables 4.5 and 4.6 show changes in temperature, precipitation, cloud cover, relative humidity, average wind speed and sea level for HadRM3 grid points close to London. Changes are all with respect to the mean 1961-1990 climate, for the UKCIP02 **Low Emissions** and **High Emissions** scenarios respectively. The scenarios presented in Tables 4.5 and 4.6 should be regarded only as indicative because the regional climate model treats London as a vegetated surface. Furthermore, the use of model results from individual grid points is generally discouraged by the climate modelling community.

Table 4.5 Climate changes for Greater London* under the UKCIP02 Low Emissions scenario

Variable	2020s			2050s			2080s		
	Summer	Winter	Annual	Summer	Winter	Annual	Summer	Winter	Annual
Temperature (ºC)	1 to 1.5	0.5 to 1	0.5 to 1	2 to 2.5	1 to 1.5	1.5 to 2	2.5 to 3	1.5 to 2	2 to 2.5
Precipitation (%)	-10 to -20	0 to 10	-10 to 0	-30 to -20	10 to 15	-10 to 0	-30 to -20	10 to 15	-10 to 0
Cloud cover (%)	-4 to -3	nv	-3 to -2	-6 to -5	nv	-4 to -3	-9 to -6	nv	-6 to -3
Relative humidity (%)	-4 to -3	-1 to 0	-2 to -1	-6 to -5	-1 to 0	-4 to -2	-9 to -6	-3 to 0	-6 to -3
Wind speed (%)	0 to 1	1 to 2	0 to 1	0 to 1	2 to 3	0 to 1	0 to 3	3 to 5	nv
Net sea level change (cm)	12			19			26		

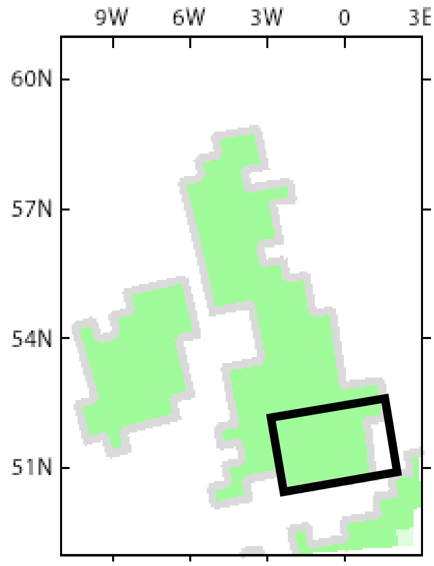
* estimated from the model grid points closest to Greater London
nv indicates changes within the bounds of 'natural variability'

Table 4.6 Climate changes for Greater London under the UKCIP02 High Emissions scenario

Variable	2020s			2050s			2080s		
	Summer	Winter	Annual	Summer	Winter	Annual	Summer	Winter	Annual
Temperature (ºC)	1 to 1.5	0.5 to 1	1 to 1.5	3 to 3.5	1.5 to 2	2 to 2.5	>4.5	3 to 3.5	4 to 4.5
Precipitation (%)	-20 to -10	0 to 10	-10 to 0	-40 to -30	15 to 20	-10 to 0	<-50	25 to 30	-10 to 0
Cloud cover (%)	-4 to -3	nv	-3 to -2	-10 to -8	nv	-6 to -4	<-15	0 to 3	-9 to -6
Relative humidity (%)	-4 to -3	-1 to 0	-3 to -2	-10 to -8	-2 to 0	-6 to -4	-15 to -12	-3 to 0	-9 to -6
Wind speed (%)	0 to 1	2 to 3	0 to 1	0 to 2	3 to 5	0 to 2	0 to 3	7 to 9	0 to 3
Net sea level change (cm)	22			48			86		

In addition, UKCIP02 projections of temperature and precipitation changes were extracted for a domain covering south-east England (Figure 4.1). Patterns are presented for the **Low Emissions** and **High Emissions** scenarios, for different seasons, and for three future periods: 2020s (years 2011 to 2040), 2050s (2041 to 2070), and 2080s (2071 to 2100). All changes are expressed with respect to the average 1961-1990 climate, which itself may incorporate some climate change. The **Low Emissions** and **High Emissions** scenarios represent the full range of precipitation and temperature change under the UKCIP02 scenarios, but not the full range of emission scenarios shown in the IPCC TAR.

Figure 4.1 Reference map showing the south-east region used herein with respect to the UKCIP02 domain



Temperature

By the 2080s, annual temperatures average across the south-east UK may rise by about 2.2ºC for the **Low Emissions** and by about 4.2ºC for the **High Emissions** scenario (see Figure 4.2). In general, there may be a greater warming in summer and autumn than in winter and spring, and there may be greater warming during night in winter and during day in summer. This implies that heating degree days will decrease, and that cooling degree days will increase. The likelihood of extreme temperatures is also expected to increase. For example, the summer maximum temperature that has a 5% chance of occurring on a given day under the current climate may increase from about 28ºC to 36ºC by the 2080s under the **Medium-High Emissions**.

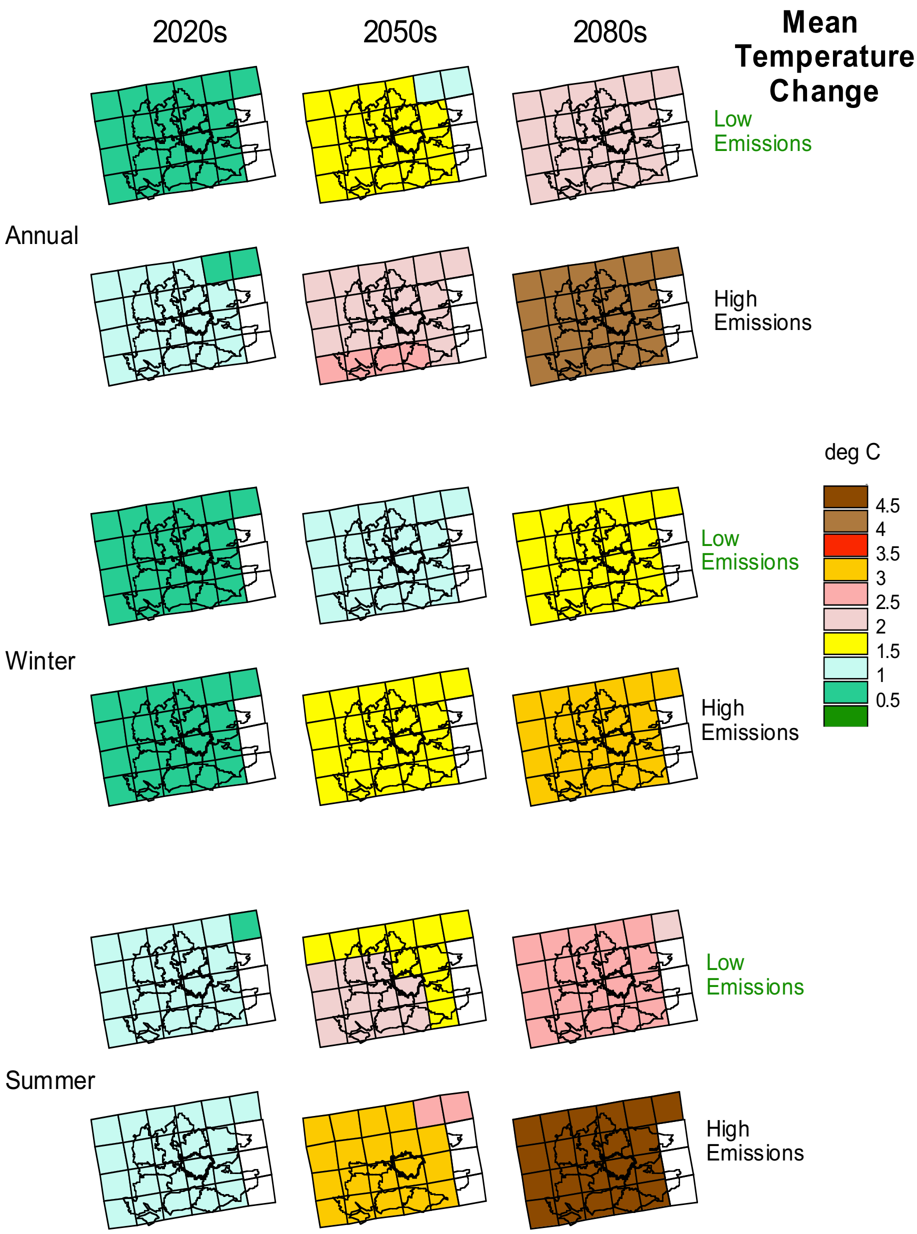


Figure 4.2 Changes in south-east England average annual, winter and summer temperature for the 2020s, 2050s and 2080s for the UKCIP02 Low Emissions and High Emissions **scenarios**

Note: Although the colour code is consistent with UKCIP02 figures, there are slight differences between the plots shown above and those in the UKCIP02 report. This is because the monthly mean data held on the UKCIP02 website has been smoothed using a 1-2-1 filter (e.g., smoothed Jan mean = [Dec mean + 2*Jan mean + Feb mean]/4) to reduce step changes between months. This smoothing was not undertaken for data used in the maps of the UKCIP02 report (Turnpenny, pers. comm.)

Precipitation
By the 2080s, winter precipitation in the south-east may increase by 10 to 20% for the **Low Emissions** scenario, to between 25 to 35% for the **High Emissions** scenario (see Figure 4.3). The pattern is reversed in summer, with a decrease in rainfall for the **Low Emissions** scenario of up to 30%, and by 50% or more for the **High Emissions** scenario. The net effect on annual precipitation totals, is a reduction of 5 to 10%. There will also be less snowfall over the south-east – perhaps up to 90% reductions by the 2080s for the **High Emissions** scenario, and 50-70% reductions for the **Low Emissions** scenario. The frequency of heavy winter precipitation, however, is projected to increase. For example, the maximum daily precipitation amount that currently occurs once every two winters may increase in intensity by between 10 to 20% for the **Low Emissions** scenario and by more than 20% for the **High Emissions** scenario.

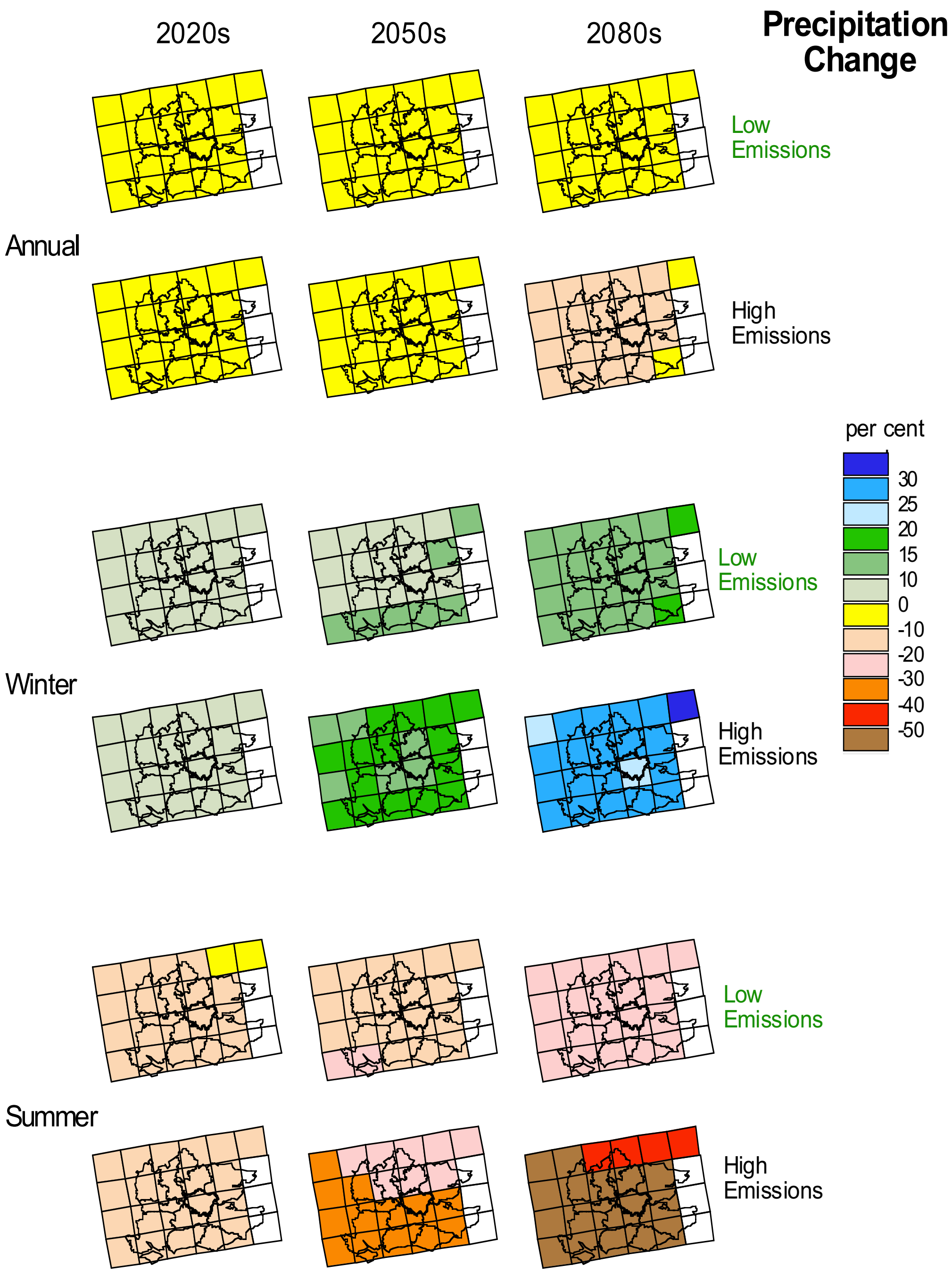


Figure 4.3 As in Figure 4.2, but for precipitation

Sea Level
Rates of change in mean sea level around the UK depend on natural land movements as well as on the thermal expansion of the world's oceans and melting of land glaciers. By the 2080s the net sea-level rise (taking vertical land movements into account) for London may be 26 cm under the **Low Emissions** scenario and 86 cm under the **High Emissions** scenario, relative to 1961-1990. These values were derived using the low end of the **Low Emissions** scenario (9 cm global sea-level rise) and the high end of the **High Emissions** scenario (69 cm rise), plus an assumed vertical land change of 1.5 cm/decade. However, most coastal damage is caused during storm surges. According to the Proudman Oceanographic Laboratory model, the 1 in 50 year extreme sea level increases by more than 1.1 metres by the 2080s under the **Medium-High Emissions** scenario. Unfortunately, much uncertainty is associated with this result, because the projections depend very much on the particular ocean model used.

Other Variables
Tables 4.5 and 4.6 provide summary information on projected changes in other climate variables for the south-east. By the 2080s, cloud cover may decrease in summer by more than 15% for the **High Emissions** scenario, with concomitant increases in summer sunshine. Summer relative humidities reduce by 10% or more for the **High Emissions** scenario, with fewer fog days expected in winter. Wind speeds are highly problematic to estimate from climate models, however, the UKCIP02 scenarios suggest that more frequent depressions cross the UK in winter leading to stronger winds in southern England. Finally, average soil moisture will decrease by 40% or more under the **High Emissions** scenario, and by about 20% for the **Low Emissions** scenario.

4.4 Climate Change Analogues

The future weather will continue to display much natural year-to-year and decade-to-decade variability. Indeed, for some aspects of climate, such as precipitation, natural variations are expected to be greater than changes due to increased greenhouse gas emissions until the second half of the 21st century. One helpful approach to visualising future probabilities of selected seasonal climate extremes is to describe their occurrence with reference to Table 4.3 events in the past. Climate change analogues are thus constructed by identifying climate records that could typify the future climate of the region. A major advantage of the approach is that the future climate scenario (and accompanying environmental impacts) may be described in far greater temporal and spatial detail than might otherwise be possible (see Subak et al., 1999). For example, the hot/dry summer of 1995 and the wet winter of 1994/95, provide useful analogues of the projected climate of the 2050s (Table 4.7). Thus, by the 2050s, the '1995-type' summer might be expected to occur in one year out of five, and by the 2080s, two in every three years.

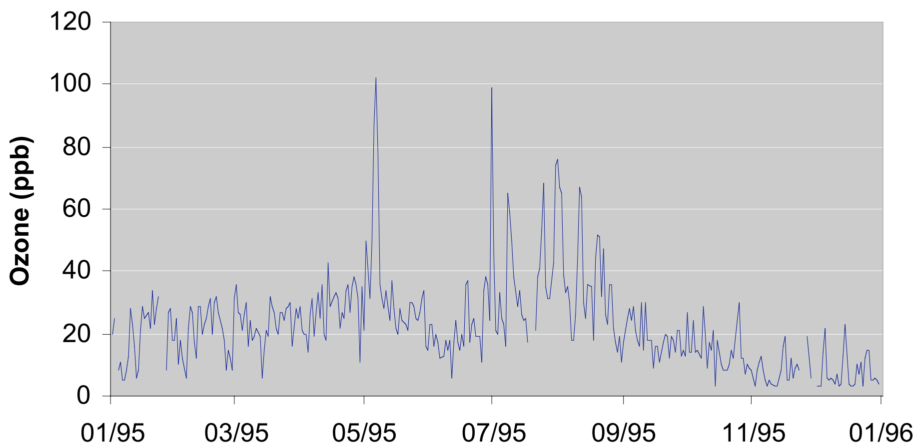
Table 4.7 Percentage of years experiencing extreme seasonal anomalies across central England and Wales for the Medium-High Emissions scenario

Analogue	Anomaly	2020s	2050s	2080s
A hot '1995-type' August	3.4ºC warmer	1	20	63
A warm '1999-type' year	1.2ºC warmer	28	73	100
A dry '1995-type' summer	37% drier	10	29	50
A wet '1994/95-type' winter	66% wetter	1	3	7

The anomalies shown are relative to the average 1961-1990 climate.
Source: Hulme et al. (2002)

A major disadvantage of the analogue approach is that the associated impacts of the weather extreme are unlikely to be the same in the future. For example, the summer of 1995 resulted in several serious ozone episodes in London (Figure 4.4). The development of similar pollution episodes in the summers of the 2050s, presupposes that the historic combination of emissions and large-scale weather systems are repeated.

Figure 4.4 Maximum hourly mean ozone concentrations at Russell Square Gardens, Bloomsbury, London during the hot-summer year of 1995. The World Health Organisation (WHO) guideline of 76 ppb was breached on five occasions during 1995.



4.5 Statistical Downscaling

Climate change scenarios for individual sites may differ from those represented by the climate model grid-boxes shown in Figures 4.2 and 4.3. This is because the former are point statistics, whereas the latter are area-averages. Statistical downscaling (SDS) methods are relatively simple procedures for translating large-scale climate model information into station scale data representing the unique 'local' climate of target sites (for a review see Wilby and Wigley, 1997). This enables the development of climate change scenarios of higher resolution than available through UKCIP02, and at scales commensurate with many impact sectors. The technique involves two main steps. Firstly, statistical relationships are established between the target variable of interest (e.g., maximum daily temperatures in St James Park, London) and indices of regional weather (e.g., wind direction, atmospheric pressure, etc., over southern England) for the *current* climate (Figure 4.5). Secondly, the same statistical relationships are employed to estimate the local variable for the *future* climate, using data supplied by a climate model. SDS techniques are not computationally demanding and require orders of magnitude *less* computer time than RCMs to produce equivalent scenarios. However, SDS scenarios are dependent on the stability of the local–regional scale relationship(s), and on the choice of predictor variable(s) used for downscaling future climate change (see Winkler et al., 1997).

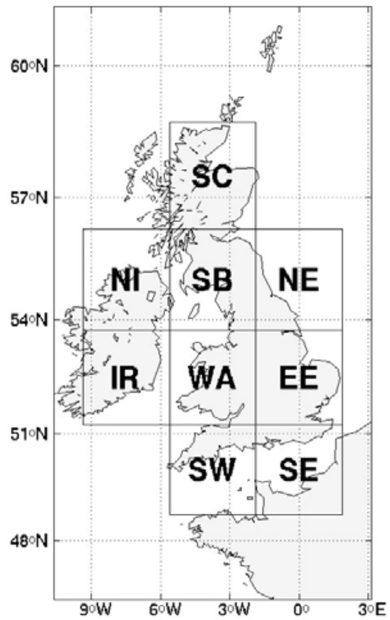
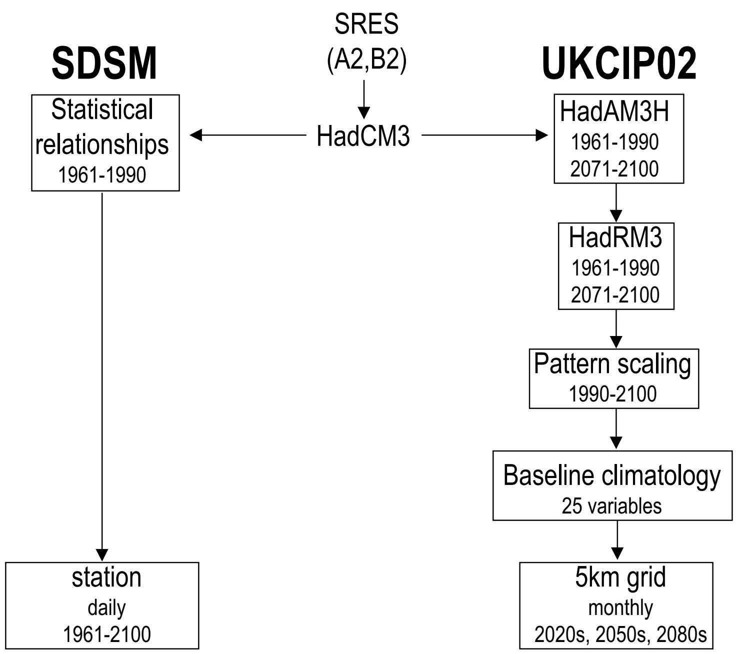


Figure 4.5 The location and nomenclature of the nine climate model grid boxes used for downscaling current and future climate scenarios to individual sites across the UK. Downscaling for London was undertaken using climate information taken from the EE and SE grid-boxes.

The local climate scenarios used for impacts assessment in subsequent sections of this report were developed using the **S**tatistical **D**own**S**caling **M**odel (SDSM) version 2.2 (Wilby et al., 2002). This software facilitates the rapid development of multiple, low–cost, single–site scenarios of daily surface weather variables under current and future climate conditions. An important feature of the SDSM package is the data archive: a set of daily climate variables prepared for model calibration and downscaling to any site across the UK (Figure 4.5). This archive contains variables describing atmospheric circulation, thickness, stability and moisture content at several levels in the atmosphere, under climate conditions observed between 1961 and 2000. Equivalent predictor variables are provided for HadCM3 experiments of transient climate change between 1961 and 2099, for the A2 (**Medium-High Emissions**) and B2

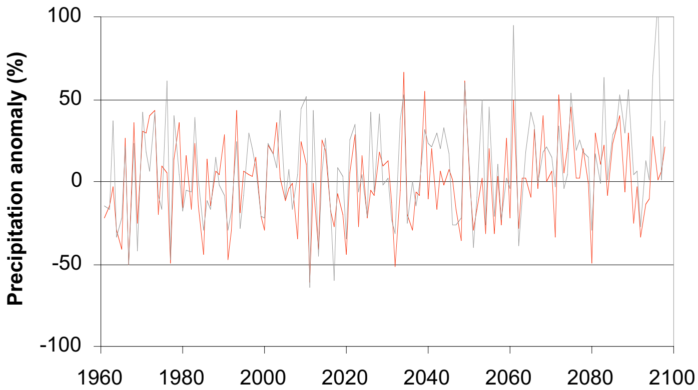
(**Medium-Low Emissions**) SRES scenarios. As Figure 4.6 shows, both the SDSM and UKCIP02 scenarios ultimately derive from the same climate model experiments – what is different is the means by which the HadCM3 climate model output is translated to finer spatial scales. The former yields point and sub-grid scale (<50 km) information from statistical relationships; the latter uses a combination of nested dynamical modelling (via HadAM3H and HadRM3) and pattern-scaling techniques.

Figure 4.6 Comparison of SDSM and UKCIP02 methodologies and scenario products. Note that HadAM3H predictors were not used for statistical downscaling in the present study, but these may become available in due course.



Although the UKCIP02 and SDSM scenarios will be broadly consistent, subtle variations are expected on a season-to-season basis (see Figure 4.7), with greatest differences for extreme events occurring at daily time-scales (e.g. precipitation). The year-to-year (transient) evolution of the climate scenario is also of interest. For example, in the case of Kew, both the downscaled and coarse resolution climate model scenarios show that large negative winter precipitation anomalies can still occur in the 2080s even though the underlying trend in winter precipitation is upwards. Extreme seasons that ‘buck’ the underlying trend would be overlooked by any downscaling method that simply reports thirty-year climate averages for the 2020s, 2050s and 2080s.

Figure 4.7 Winter (December to February) precipitation anomalies (%) for the Eastern England grid box of HadCM3 (grey) compared with a downscaled (red) scenario for Kew, both from the Medium-High Emission scenario. The downscaled scenarios were produced using the Statistical DownScaling Model (SDSM) forced by HadCM3 predictor variables from the A2 experiment (http://www.sdsm.org.uk/). Anomalies were calculated with respect to the 1961-1990 averages.



4.6 Key Uncertainties

Before the potential impacts of the UKCIP02 and SDSM climate changes for London are discussed, it is imperative that the key uncertainties attached to the scenarios be identified:

- Although the emissions used as the basis of the UKCIP02 scenarios represent the full range reported by the IPCC (2001), the scenarios available herein for statistical downscaling (just the **Medium-High Emissions** and **Medium-Low Emissions** scenarios) represent a narrower range. It is also currently impossible to assign probabilities to the various emission scenarios.

- There are a large number of scientific uncertainties concerning the future behaviour of emitted greenhouse gases, the significance of aerosols and soot particles, carbon-cycle feedbacks and ocean responses to greenhouse gas forcing. Different global and regional climate models will, therefore, produce different results depending on the treatment of these factors. The HadCM3 model produces rainfall changes close to the model range for winter, but simulates a larger reduction in summer rain than most models. Such inter-model differences over the UK may be expressed as uncertainty margins to be applied to the UKCIP02 scenarios of *change* in temperature and precipitation (Table 4.8).

Table 4.8 Suggested uncertainty margins to be applied to the UKCIP02 scenarios of changes in average winter and summer temperature and precipitation

	Low Emissions	Medium-Low Emissions	Medium-High Emissions	High Emissions
Average Temperature				
Winter (ºC)	±0.5	±1.0	±1.5	±2.0
Summer (ºC)	±0.5	±1.0	±1.5	±2.0
Average Precipitation				
Winter (%)	±5	±10	±15	±20
Summer (%)	+10	+15	+30	+40

Note: all summer rainfall sensitivities are positive because UKCIP02 summer rainfall changes are already considered to be at the drier end of the inter-model range.
Source: Hulme et al. (2002).

- The realism of the UKCIP02 and SDSM scenarios ultimately depend on the realism of the HadCM3 model output from which both are derived. Fortunately, the performance of this model, when assessed using a range of pattern correlation techniques, is consistently amongst the world's best for the current climate (Wigley and Santer, *pers. comm.*).

- There is little agreement amongst different models about regional patterns of sea-level rise. This is because of regional variations in the warming of ocean water (and associated thermal expansion), ocean circulation and atmospheric pressure. In UKCIP02, future changes in mean sea level were derived using local rates of natural land movement (subsidence) together with the full range of UKCIP02 global sea level rise for the three future periods. This idealised approach does not include any variations in regional sea level rise due to changing estuary shape, sediment consolidation or wave heights, so an uncertainty margin of ±50% is attached to each scenario of sea level rise in Table 4.5 and 4.6.

- Most climate models, including HadCM3, suggest a weakening (but not a shut-down) of the north Atlantic Gulf Stream over the next 100 years. However, changes in the salinity and temperature profile of north Atlantic surface waters, could in theory lead to a shut-down of the Gulf Stream. Although a cooling of UK climate over the next 100 years because of a shut-down of the Gulf Stream is considered unlikely, it can not be completely ruled out.

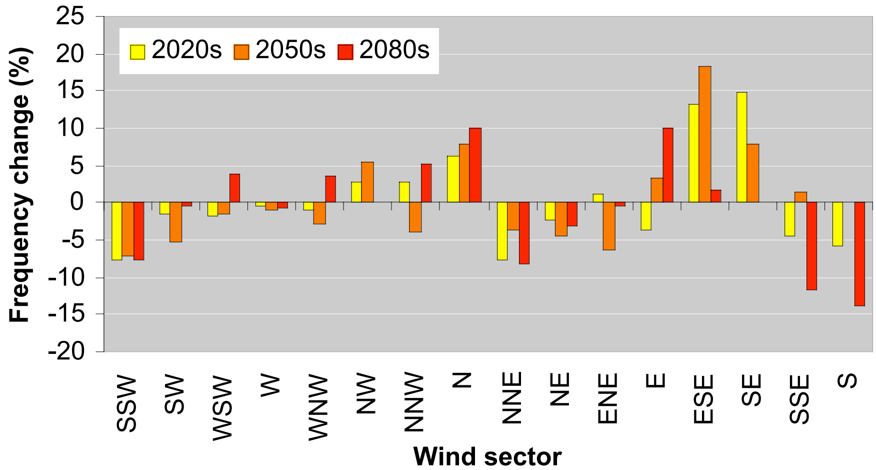
These factors should be borne in mind when considering the following set of climate change impacts for London.

4.7 Statistical Downscaling Case Study: Changes to London's Heat Island Intensity

The existing models of climate change assume a rural land cover. This makes them of limited use for estimating the climate change impacts in urban areas, especially London. This project has estimated changes to the Heat Island Effect, but obviously given the limitations in time and resources available in this project, this has not been a comprehensive remodelling of climate change for London. It is to be hoped that the effects of urban areas will be included in future climate change modelling work. Most people live in cities and urban areas and it is therefore critical to accurately determine the effects of climate change to these built up areas.

Early surveys of London's heat island indicated that the peak usually lies north-east of central London in Hackney and Islington, reflecting the density of urban development, and the displacement of the heat-island by prevailing south-westerly winds (Chandler, 1965). More recent monitoring has highlighted the mobility of the peak in relation to hourly shifts in wind direction (Graves et al., 2001). The thermal centre typically moves by several kilometres in line with the change in wind direction, therefore, future changes in the frequency of different wind directions could have an impact on the future location of the thermal centre. Figure 4.8 indicates a general increase in airflows from the east and south-east at the expense of airflows from the south and south-west under the Medium-High Emissions scenario. This implies that the thermal centre could lie more often over the west and north-west sectors of the City. However, this inference should be treated with extreme caution because the storm tracks in HadCM3 are known to be displaced too far south over Europe, adversely affecting the realism of modelled airflows over southern England (Hulme et al., 2002). Furthermore, projected changes in airflow are generally small relative to natural variability.

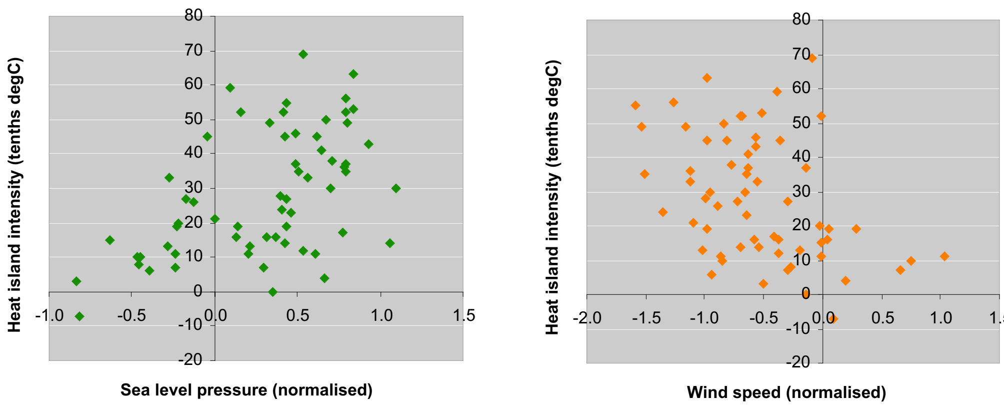
Figure 4.8 Per cent changes in the frequency of daily airflows over the Eastern England grid box (see Figure 4.5) under the Medium-High Emissions scenario by 2020s, 2050s and 2080s. Changes are with respect to the 1961 to 1990 average



The intensity of London's nocturnal heat island has been modelled using daily minimum temperatures for St James's Park (urban site) and Wisley in Surrey (rural reference station 30 km to the southwest). The average nocturnal heat island intensity for the period 1961 to 1990 was +1.8ºC, ranging from +10.0ºC (on 14 January 1982) to –8.9ºC (on 31 May 1970), with 5% of days having an intensity of 5ºC or more. In comparison, the average day-time heat island intensity was just +0.3ºC, ranging between +11.7ºC (on 30 May 1963) and –6.7ºC (on 12 December 1963).

The statistical downscaling model SDSM was calibrated using 1961 to 1990 daily minimum temperature differences between St James's and Wisley, and climate variables for the Eastern England (EE) grid-box (Figure 4.5). Significant correlations were found between the intensity of the heat island and several regional climate indices (most notably mean sea level pressure, strength of airflow, vorticity and near surface relative humidity). For example, Figure 4.9 shows the relationship between the nocturnal heat island intensity and pressure/wind speed during the summer of 1995. The scatterplots show that the intensity is greater under conditions of high pressure and low wind speeds (i.e., anticyclonic weather). Interestingly, the nocturnal heat island intensity is only weakly correlated with regional temperatures, suggesting that future changes in the heat island will be largely independent of projected temperature changes.

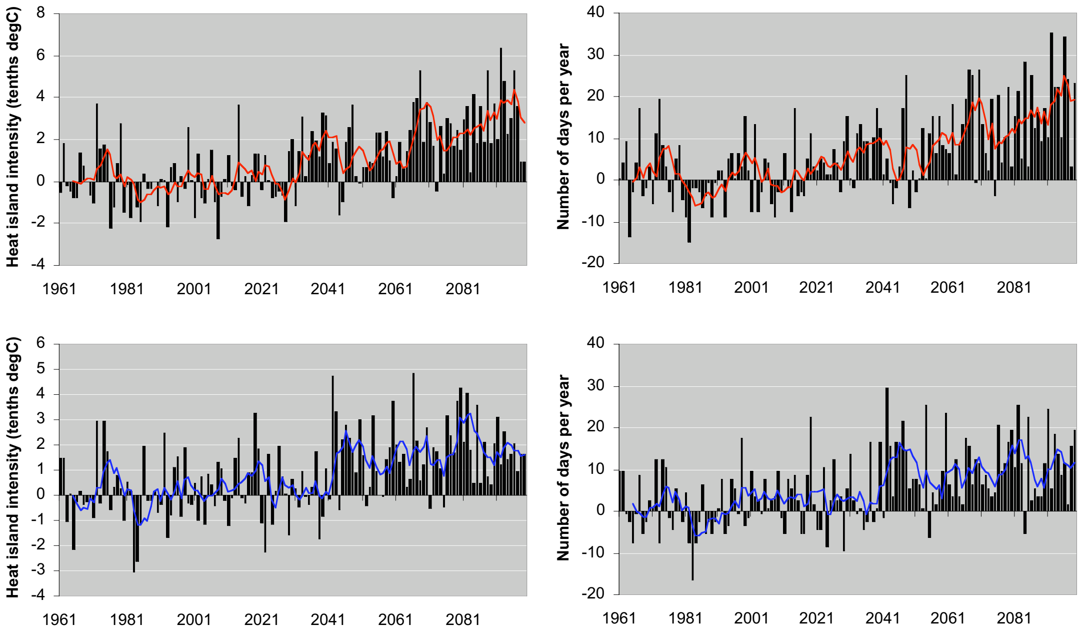
Figure 4.9 The relationship between London's nocturnal heat island intensity and sea level pressure, and wind speed, July to August 1995



Having established the historic relationship between the nocturnal heat island intensity and regional weather, the statistical downscaling software SDSM (Wilby et al., 2002) was then used to produce future estimates of the heat island under the Medium-High Emissions and Medium-Low Emissions scenarios. Under both scenarios there are progressives increases in both the intensity (i.e., annual average temperature difference between the sites) and number of days on which the intensity exceeded 4ºC (Table 4.9). In line with past experience, there remains considerable interannual variability in both measures (Figure 4.10). Under the Medium-High Emissions scenario, the nocturnal heat island intensity increases by 0.26ºC and the number of intense urban-rural differences by 15 days/year by the 2080s. Note that these heat island temperature changes are in *addition* to the regional warming shown in Figure 4.2, and relate to annual averages (Table 4.9). For example, as a first-order approximation for introducing heat island effects, the additional annual average temperature increase for London relative to rural sites in the region could be ~ 2.1ºC under the Medium-Low Emissions scenario (i.e., 1.8ºC from

1961-90 plus 0.26ºC intensification by the 2080s). However, observed data suggest that the most intense nocturnal heat islands develop in summer, and that these could have more adverse consequences for London in the future, including reduced night-time relief during heat-waves, and reduced ambient cooling of the underground system.

Figure 4.10 Change in annual average nocturnal heat island intensity (left column) and the number of intense (>4ºC urban-rural difference) heat island days (right column) in



central London (Medium-High Emissions [top row], and Medium-Low Emissions [bottom row], downscaled), with respect to the 1961 to 1990 average

Table 4.9 Changes in the average nocturnal heat island intensity, net temperature† and, change in the number of intense (>4ºC urban-rural difference) heat island days in central London (Medium-High Emissions, and Medium-Low Emissions, downscaled), for the 2020s, 2050s and 2080s with respect to the 1961 to 1990 average

	Medium-High Emissions			Medium-Low Emissions		
Scenario	**_Intensity (ºC)**	**_Temperatur (ºC)**	**_Frequency (days)**	**_Intensity (ºC)**	**_Temperature (ºC)**	**_Frequency (days)**
2020s	0.07	2.4 – 2.9	5	0.03	2.3 –2.8	3
2050s	0.16	4.0 – 4.5	9	0.17	3.5 – 4.0	10
2080s	0.26	5.6 – 6.1	15	0.19	4.5 – 5.0	11

† Change in net temperature = baseline heat island (1961-1990) + heat island intensification (by date) + regional warming (by date)

4.8 Bibliography

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5. The Potential Environmental Impacts of Climate Change in London

5.1 Introduction

There are several approaches to climate change impact assessment. These include: extrapolating findings from existing literature; fully quantitative, model-based simulations of the system(s) of interest; or eliciting the opinions of experts and stakeholders. All three approaches will be implemented in this section by a) reviewing the formal literature where appropriate, b) undertaking exemplar impacts modelling for specific issues identified through c) dialogue with stakeholders. Two workshops were held in May 2002 in order to engage expert and stakeholder opinion regarding the most pressing potential climate change impacts facing London. Following stakeholder consultation, five environmental areas were highlighted: 1) urban heat island effects (including London Underground temperatures); 2) air quality; 3) water resources ; 4) tidal and riverine flood risk and 5) biodiversity. Although these are addressed in turn – and where appropriate, case studies have been included – it is also acknowledged that many of these are cross-cutting (for example, river water quality impacts relate to flood risk, water resources and biodiversity). The final section delivers a summary of the most significant environmental impacts of climate change for London. Policy responses are addressed elsewhere.

5.2 Higher Temperatures

5.2.1 Context

Throughout this section the reader is invited to refer to the downscaling case study provided in Section 4.7). Heat waves may increase in frequency and severity in a warmer world. Urban heat islands exacerbate the effects of heat waves by increasing summer temperatures by several more degrees Celsius relative to rural locations (see Figure 3.2b). This can lead directly to increases in mortality amongst sensitive members of the population (Kunst et al., 1993; Laschewski and Jendritzky, 2002). For example, the heat waves in the summers of 1976 and 1995 were associated with a 15% increase in mortality in greater London (Rooney et al., 1998). Conversely, it has been estimated that 9000 wintertime deaths per year could be avoided by 2025 in England and Wales under a 2.5ºC increase in average winter temperatures (Langford and Bentham, 1995).

5.2.2 Stakeholder Concerns

Rising ambient air temperatures in central London may have significant impacts on air temperatures experienced across the London Underground network. However, projecting future summer temperatures in the network is not straightforward because the outcome depends on assumptions about the number of passengers, frequency of trains, station design and depth below the surface, as well as on air humidity and levels of ventilation (typically low, with mixing ratios ~10%). Furthermore, passenger comfort often reflects the difference in temperature between above ground, the stations and the trains, rather than the absolute temperature *per se*. Nonetheless, an intensified heat island combined with regional climate warming, could pose difficulties for the future operation of cooling and ventilation equipment. The siting of intakes, for example, must take into account the vertical heat profile, whilst cooling effectiveness is largely governed by minimum ambient air temperature. (The Chartered Institute of Building Services Engineers has recently revised design temperatures from 28ºC to 30ºC). Although some data and model results are available for the new terminal at King's Cross, there are no long-term temperature records for the wider network. Until such monitoring systems are in place, claims of rising underground temperatures and possible links to climate change will remain largely anecdotal.

In addition to the issues raised above, stakeholder engagement highlighted further potential impacts related to increased urban temperatures arising from the *combined* effect of regional climate change and an intensified urban heat island (Table 5.1).

Table 5.1 Potential temperature related impacts identified by stakeholders

Associated Impacts
• Increased demand for water for irrigating green spaces;
• Higher risk of fires on scrub and heathland;
• Lower incidence of winter 'fuel poverty' and related cold-weather mortality;
• Outdoor lifestyles change levels of exposure to air pollution (see below);
• Modes of transport could shift (more walking and cycling);
• Energy use for summer cooling could exceed energy saved through less winter warming;
• Higher rates of refuse decay implying need for more frequent waste collection;
• Successive hot summers could have a compound impact exceeding isolated hot summers.

•

A case study of changes to London's heat island intensity is given in Section 4.7.

5.2.3 Adaptation Options

There exist a range of established but non-trivial techniques for countering the effect of rising temperatures in urban areas. These include: reducing building densities; changing building height, spacing and street orientation to increase shade and reduce insolation receipt; enhancing natural ventilation through a variation of building height and density; achieving effective solar shading using trees and vegetation; use of high-albedo (reflective) building materials; improved building and cooling system design; and incorporation of large areas of vegetation and water features within the urban landscape (Oke, 1987). For example, detailed monitoring shows that air moving along the edge of the River Thames, or within urban parks, is on average 0.6ºC cooler than air in neighbouring streets (Graves et al., 2001). In Chicago's Urban Heat Island Initiative there is a programme of greening hard spaces by installing rooftop gardens and replacing hard surfaces such as school playgrounds with grassed areas (see: http://www.cityofchicago.org/Environment/AirToxPollution/UrbanHeatIsland/). As well as countering urban heat island effects, more widespread green space and vegetation in the City is also beneficial for flood control (see Section 5.5.3).

5.3 Air Quality

5.3.1 Context

Air pollution is already a serious health problem in many cities even under the current climate (Anderson et al., 1996; COMEAP, 1998). Climate change is expected to cause further deterioration in air quality in large urban areas. This is because future weather will have a major influence on the production, transport and dispersal of pollutants. Any increase in the frequency of hot, anticyclonic weather in summer will favour the creation of more temperature inversions trapping pollutants in the near-surface layer of the atmosphere. For example, it has been estimated that a 1 degree Celsius rise in summer air temperatures (also a proxy for the amount of catalysing sunshine) is associated with a 14% increase in surface ozone concentrations in London (Lee, 1993).

Higher air temperatures increase natural and man-made emissions of volatile organic compounds (VOCs) (Sillman and Samson, 1995), exacerbating the health effects of ozone pollution (Sartor et al., 1995). Climate change is also expected to affect the seasonality of pollen-related disorders such as hay fever (Emberlin, 1994). Meteorological factors are shown to exert strong controls on the start date and length of the pollen season (Emberlin, 1997), as well as the total pollen count (Takahashi et al., 1996). Acute asthma epidemics have also been linked to high pollen levels in combination with thunderstorms (Newson et al., 1998). During one such event in 1994 London health departments ran out of drugs, equipment and doctors (Davidson et al., 1996). Finally, deteriorating air quality as a result of climate change could have secondary impacts on the vitality of urban forests and parkland. For example, surface ozone has adversely impacted the structure and productivity of forest ecosystems throughout the industrialised world (Krupa and Manning, 1988). Levels of acid deposition are also closely linked to the frequency of large-scale weather patterns across the UK (Davies et al., 1986).

5.3.2 Stakeholder Concerns

In addition to the issues raised above, stakeholder engagement highlighted further potential air quality impacts related to climate change (Table 5.2).

Table 5.2 Potential air quality impacts identified by stakeholders

Associated Impacts
• Outdoor lifestyles change levels of exposure to air pollution; • Air pollution damages building fabric and aesthetics of urban landscapes; • Homeowner preference for relatively unpolluted suburbs (but higher ozone levels here); • Indoor and underground air quality may change; • Greater incidence of fire-related air pollution (smoke); • Higher dust and VOC concentrations are associated with building programmes; • Greater odour problems associated with waste disposal and standing water bodies; • Export of pollution to surrounding regions through increased tourism and air travel.

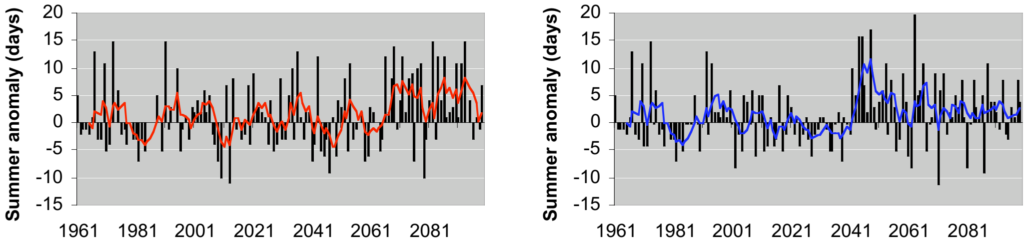
5.3.3 Case Study

Changes in the frequency of weather-related pollution episodes

As noted previously, weather patterns are a strong determinant of ambient air quality and pollution episodes (O'Hare and Wilby, 1994). Therefore, future air pollution concentrations in London will reflect local and regional patterns of emissions, as well as the frequency of large high-pressure systems over the south-east. Whilst it is beyond the scope of the present study to model the complex interactions between pollutant emissions, photochemistry, transport and dispersal, it is possible to speculate about the future frequency of 'pollution-favouring' weather patterns. Whereas vigorous westerly airflows favour the dispersal of pollutants, stagnant anticyclonic weather provides ideal conditions for *in situ* pollution episodes (e.g., Bower et al., 1992).

Figure 5.1 shows the change in the frequency of high pressure systems over the EE grid-box (Figure 4.2) under the Medium-High Emissions and Medium-Low Emissions scenarios. Under the Medium-High Emissions there is an average increase in the frequency of pollution episodes of over 4 days per summer by the 2080s compared with the 1961 to 1990 mean. The change under the Medium-Low Emissions is a little over 2 days per summer by the 2080s. A shift to more frequent airflows from the east and south-east (shown in Figure 4.8) would also favour more frequent incursions of (polluted) air from continental Europe (O'Hare and Wilby, 1994). However, Figure 5.1 indicates considerable inter-annual variability in the frequency of summer pollution episodes, and caveats related to future airflows projections by HadCM3 apply (see Section 5.2). Notwithstanding significant reductions of diffuse emissions over north-west Europe, the model projections are still indicative of deteriorating air quality conditions for London under future climate change.

Figure 5.1 **Change in the number of summer weather patterns favouring pollution episodes over the Eastern England grid-box under the Medium-High Emissions (left column) and Medium-Low Emissions (right column) scenarios, with respect to the 1961 to 1990 average.**



5.3.4 Adaptation Options

Actions to improve air quality in London cannot be considered in isolation from those designed to reduce greenhouse gas emissions, however, more attention needs to be paid to diffuse sources - in particular, those linked to the transport infrastructure (Wade et al., 2001). This could take the form of: new fiscal and voluntary initiatives to control emissions; traffic restrictions; improved public transport systems; incentives to promote carpooling; pollution warning services (e.g. London Air Quality Network, http://www.erg.kcl.ac.uk/london/asp/home.asp). Such endeavours should be underpinned by regional inventories of pollution sources, as well as by systems for continuous monitoring of key pollutants and relevant weather variables.

The Association of London Government is working with the Greater London Authority and others on a feasibility study for creating a Low Emission Zone for London which would ban disproportionately polluting vehicles such as heavy goods vehicles, This would be done using statutory mechanisms. A licensing regime to clean up buses and taxis is also being considered.

5.4 Water Resources

5.4.1 Context

Climate induced changes in water resources may have far reaching consequences for society, the economy and terrestrial ecosystems. Global patterns of change are broadly in line with changes in annual precipitation, resulting in decreased summer soil moisture (Gregory et al., 1997) and annual runoff at mid-latitudes (Arnell, 1999). However, it is important to recognise that natural variations in rainfall-runoff (which are typically large) can exceed human-induced climate changes to runoff for many regions (Hulme et al., 1999). At the national scale, several studies have suggested increases in UK winter runoff, accompanied by decreases in summer runoff, most notably in the south (Arnell, 1998; Arnell and Reynard, 1996; Pilling and Jones; 1999; Sefton and Boorman, 1997). Most recently, the UKCIP02 scenarios indicate a decrease in average soil moisture both annually and in summer that is most severe, again, in the southeast (Hulme et al., 2002). In the Thames region, 55% of the effective rainfall that falls annually is abstracted, amounting to about 5000 Ml/d, of which 86% is used for public water supply. Even without climate change, the present balance of supply and demand is in deficit by some 180 Ml/d (EA, 2001c).

Catchment-scale studies undertaken in the Thames region highlight the control exerted by local variations in geology (Davis, 2001; Wilby, 1994), landuse change, surface and groundwater abstraction on river flows (Wilby et al., 1994). For example, using monthly factors from the UKCIP98 scenarios, summer baseflows in chalk catchments are slightly enhanced as a result of greater winter recharge, but decline in clay and urban catchments where the potential for enhanced groundwater recharge is lower (Davis, 2001). Nonetheless, all UKCIP98 scenarios and gauging stations considered showed an overall increase to water resources of 2.5% to 6% by the 2020s, noting that by this time the temperature change is less than 1.4ºC. Unfortunately, no studies have evaluated the risks beyond the 2020s, or those associated with back-to-back drought years, to which the aquifers of the southeast are vulnerable. It is also anticipated that the (hotter/drier) UKCIP02 scenarios will yield a less favourable resource situation than UKCIP98 (see below).

Water supplies can be disrupted through deteriorating quality, and climate change has the potential to affect river water quality in several ways. For example, lower summer flows in clay catchments will reduce the volume available for dilution of treated effluent in receiving water courses, and increase the potential for saline intrusions. River water temperatures will increase with higher air temperatures, but the overall climate sensitivity will be least for catchments with large groundwater components (Pilgrim et al., 1998). Higher nutrient concentrations and river water temperatures can in turn encourage the growth of algal blooms and other plants which deoxygenate the water body. In the absence of mixing, decreased cloud cover and higher summer temperatures over the southeast also favour the thermal stratification of standing water bodies, leading to increased algal growth and raw water treatment costs (Hassan et al., 1998). Finally, warmer, drier conditions enhance the decomposition of organic nitrogen, thus increasing the potential for river and groundwater contamination (Murdoch et al., 2000). Crack formation through clay shrinkage will result in more direct hydrological links between the soil surface and groundwater, further increasing the risk of nutrient losses to aquifers (Rounsevell et al., 1999).

In addition to water availability and impact on the natural environment, climate change also affects water resource planning through changing patterns of water demand (Herrington, 1996). For example, domestic water use is expected to increase as a result of hotter summers leading to increased garden watering and personal washing. According to Environment Agency estimates, outdoor water use will increase public water supply demand in the Thames Region by approximately 50 Ml/d by 2025 due to climate change (EA, 2001c). The impact of climate change on industrial water use will be felt most keenly where consumer demand for products is temperature dependent (e.g., the food and drinks industry), or where industrial processes are less efficient at higher temperatures (e.g., water cooling for power generators).

5.4.2 Stakeholder Concerns

In addition to the issues raised above, stakeholder engagement highlighted further potential water resource impacts related to climate change (Table 5.3).

Table 5.3 Potential water resource/quality impacts and responses identified by stakeholders

- London's water supply will be affected by climate change impacts outside of the Thames Region;
- Higher winter temperatures will reduce leakage due to burst pipes as a result of freezing;
- Wetter winters will lead to expansion of clay and more leaks/bursts in the mains network;
- Drier soils and subsidence of clay soils will increase leakage in summer;
- Greater competition for finite resources between domestic and environmental needs;
- Greater variability in water supply could be reflected in seasonally variable water tariffs;
- Development of any new reservoir(s) will compete with other land use demands;
- Public health and hygiene issues associated with reduced water supply/increased cost;
- Greater use of grey water and rainwater harvesting;
- More local abstractors, treatment and usage of rising groundwater;
- Greater use of artificial groundwater recharge;
- Reluctance of metered water users to respond to water-saving appeals;
- Increased awareness of environmental 'costs' of water consumption;
- Development and deployment of more innovative water resources options;
- Increasing awareness amongst the population to use water wisely.

5.4.3 Case study

Soil moisture and water balance changes in the Rivers Kennet and Loddon

For this study, a preliminary assessment was made of potential water resource impacts for two tributaries of the Rivers Thames. Soil moisture deficits (SMDs) were modelled for the Rivers Kennet and Loddon under the Medium-High Emissions and Medium-Low Emissions scenarios (Appendix C). Figure 5.2 shows the anomalies in the annual maximum SMD, and the length of the recharge season with respect to the 1961-1990 average for the River Kennet. Table 5.4 reports mean changes in the water balance and recharge for the 2020s, 2050s and 2080s. Figure 5.3 and Table 5.5 provides equivalent results for the River Loddon. In both catchments, there is a general decline in annual precipitation of between 1 and 9% by the 2080s, accompanied by a reduction in AET of 6 to 10%, despite higher air temperatures. This apparent paradox is explained by drier summer soils limiting the rate of surface evaporation – a feature supported by recent PE observations (Marsh, 2001). The net effect of lower precipitation and reduced AET amounts is a rise in the annual maximum SMD, most notably from the 2060s onwards. Drier soils, in turn, imply more clay shrinkage induced subsidence and mains leakage (Doornkamp, 1993).

Figure 5.2 Changes in maximum soil moisture deficits (SMDs) and length of recharge season in the River Kennet catchment (Medium-High Emissions, and Medium-Low Emissions, downscaled), with respect to the 1961 to 1990 average

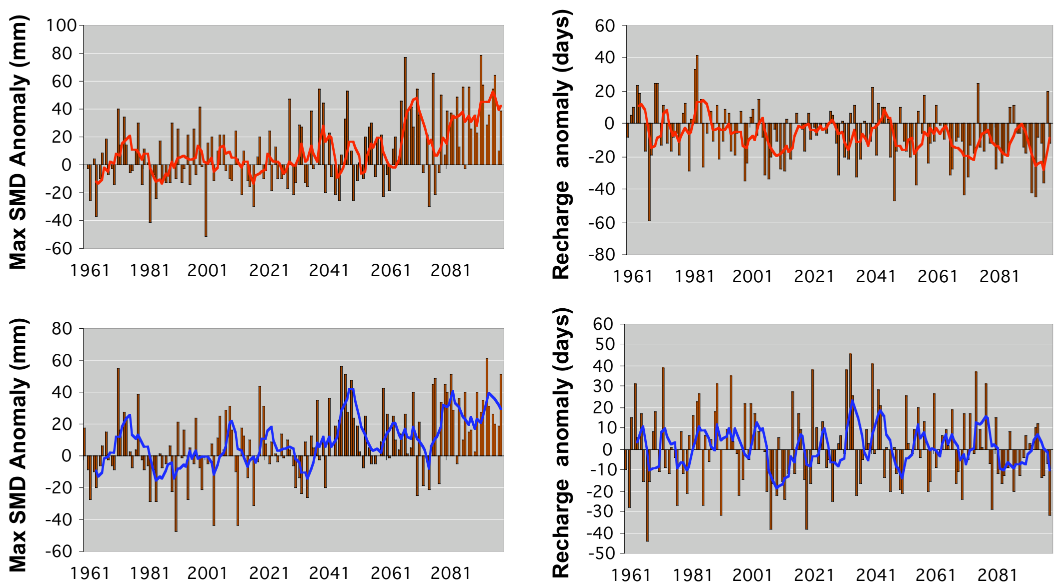
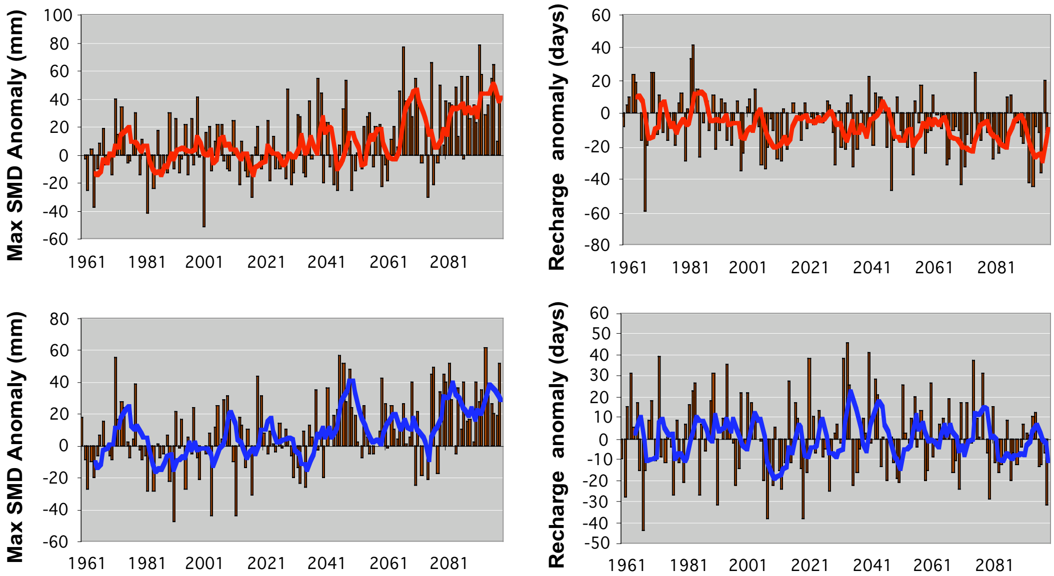


Figure 5.3 Changes in maximum soil moisture deficits (SMDs) and length of recharge season in the River Loddon catchment (Medium-High Emissions, and Medium-Low Emissions, downscaled), with respect to the 1961 to 1990 average



Drier soils at the end of the water year also mean that more precipitation is required for re-wetting to saturated conditions under which groundwater recharge or surface runoff is assumed to occur. As a consequence, the length of the recharge season declines by up to 8 days in the 2050s and by as much as 14 days by the 2080s, compared with an average recharge season of 60 days between 1961 to 1990. In the River Loddon, autumn and winter recharge declines by 4 to 6% by 2050s, and by 3 to 10% by 2080s. The change for the River Kennet is not so consistent with a 7% increase in recharge with little or no apparent change in the annual precipitation under the Medium-Low Emissions scenario, suggesting that there has been a greater concentration of precipitation during the active recharge period. In contrast, the 8% decline in precipitation under the Medium-High Emissions scenario nets a 10% reduction of recharge by the 2080s.

Finally, although runoff was not explicitly modelled in either case study it approximates recharge in the long-run (assuming zero abstraction), suggesting that the annual resource might change by between +7% (Kennet, Medium-Low Emissions) and –10% (Kennet and Loddon, Medium-High Emissions) by the 2080s.

Table 5.4 **Changes in River Kennet water balance terms, the annual maximum soil moisture deficit (SMD), and length of the recharge season under the Medium-High Emissions and Medium-Low Emissions scenarios (downscaled)**

	Precipitation (%)		Actual evaporation (%)		Recharge (%)		Maximum SMD (%)		Recharge season (days)*	
	M-H	M-L	M-H	M-L	M-H	M-L	M-H	M-L	M-H	M-L
2020s	-2	+2	0	0	-5	+6	+4	+1	-8	+1
2050s	-2	0	-2	-5	-1	+8	+10	+14	-8	+1
2080s	-8	-1	-7	-6	-10	+7	+23	+18	-14	-1

* Change in the number of days resulting in potential groundwater recharge from saturated soils

Table 5.5 **The same as Table 5.4, but for the River Loddon**

	Precipitation (%)		Actual evaporation (%)		Recharge (%)		Maximum SMD (%)		Recharge season (days)*	
	M-H	M-L	M-H	M-L	M-H	M-L	M-H	M-L	M-H	M-L
2020s	-8	+2	-3	+1	-18	+4	+8	+1	-6	-2
2050s	-3	-5	-4	-5	-3	-6	+12	+14	-5	-7
2080s	-9	-6	-10	-7	-10	-3	+27	+19	-10	-8

* Days resulting in potential groundwater recharge from saturated soils

5.4.4 Adaptation Options

Water managers are already accustomed to adapting to evolving resource situations, and extreme events in the recent hydrological record (e.g., droughts of 1921, 1934, 1976, 1988-1992, 1995-1997) provide useful analogues of future climate change. Nonetheless, there are a range of supply- and demand-side adaptive options currently under consideration for the Thames Region (EA, 2001c). On the supply-side: development of new resources including additional reservoir capacity (Abingdon), strategic bulk transfers (Grafham to Three Valleys), desalination, transfers via the Grand Union and Oxford canals, small local use of rising groundwaters and artificial recharge (in the London Basin), indirect reuse of wastewater, transfers (River Severn to Farmoor reservoirs), improved infrastructure, treatment and supply systems. On the demand-side: reductions in leakage, extension of household metering, development and promotion of water conservation measures for domestic and industrial users (including water efficient appliances), time-limited or flexible abstraction licenses. In addition, it is recommended that water efficient fittings should be a requirement of planning permissions for all new developments (Wade et al., 2001).

The question naturally arises as to what extent the Thames water resource strategy (EA, 2001c) might be affected by climate change? This can only really be answered through an integrated regional water resource modelling exercise, that incorporates more climate change detail within the Agency's four socio-economic scenarios. Alternatively, research could be targeted at critical elements in the strategy, such as modelling the reliable yield of a new reservoir, or levels of leakage, under the full set of UKCIP02 scenarios.

5.5 Flood Risk

5.5.1 Context

Both observations (Frei and Schar, 2001; Karl and Knight, 1998; Osborn et al., 2000) and climate models (Jones and Reid, 2001; McGuffie et al., 1999; Palmer and Raïsänen, 2002) support the view that the frequency and intensity of heavy rainfall increased during the 20th Century, and will continue to increase in coming decades, particularly during the non-summer seasons. However, there have been very few credible studies of riverine flood risk in relation to climate change. This is a reflection of the difficulties associated with adequately modelling high-intensity precipitation (or snowmelt) events at catchment-scales, and of representing land-surface controls of storm runoff generation (Bronstert et al., 2002).

Assessing flood risk for London is problematic, not least because of the extent of the urban drainage system, and the localised effects of blocked culverts (open watercourses which have been covered over i.e. at road crossings, culverts may also run under buildings) and/or exceedance of hydraulic capacity of sewers. In addition, future flooding of the Thames estuary will require consideration of complex interactions between sea level rise, runoff from land areas and storminess (Holt, 1999; Lowe et al., 2001; Von Storch and Reichardt, 1997). Accordingly, flood risk will be considered from three overlapping perspectives: 1) riverine flood risk; 2) the design capacity of urban drainage systems and; 3) tidal surges/sea level rise.

5.5.2 Case Study

Riverine flood risk in the Thames Region

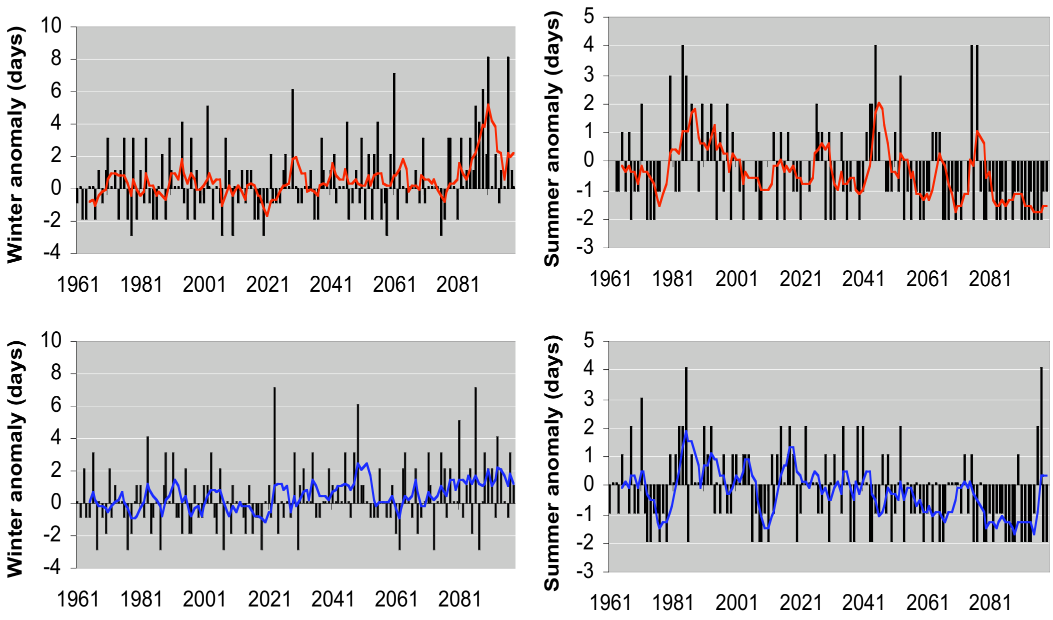
A simplistic climate change impact assessment – illustrated below – is to infer future riverine flood risk from future changes in extreme precipitation events. For example, in a recent pilot study, the regional climate model HadRM2 (the predecessor of the model used in UKCIP02) predicted future increases in the magnitude of rainfall extremes of 30- and 60-day duration (as experienced in the flooding of October/November 2000) over catchment areas influencing river levels in Lewes, Shrewsbury and York (CEH and Meteorological Office, 2001). Other studies have examined changes in effective rainfall (as a proxy for discharge) obtained directly from global climate models for large river basins (e.g., Milly et al., 2002), or downscaled meteorological variables to the scale of an experimental watershed for hydrological modelling (e.g., Pilling and Jones, 2002).

Government estimates suggest that the value of protected land and property within the Thames region tidal Thames flood risk area is £80 billion giving a flood damage estimate of the order of £30 billion (DEFRA, 2001). With growing demand for new housing in London and the preferred use of brownfield sites (often situated within the floodplain), these figures are set to increase notwithstanding changes in climate. The river defences of central London are designed to withstand floods of a 0.1% probability (i.e., a 1 in 1000 year event), however the standards of protection to some limited Thames-side areas and on many of the tributary rivers are lower. The effects of climate change are likely to reduce the standard of protection of existing defences through rising sea levels, rising groundwater, and/or increased storm magnitudes. For example, under the UKCIP98 High scenario, the 100 year return period (naturalised) daily flow at Kingston on the Thames is predicted to increase by 13% by the 2020s (Davis, 2001). Flood risk maps in catchments with significant groundwater contributions will also need to be re-evaluated in the light of enhanced winter recharge and antecedent baseflows (Wade et al., 2001).

For the purposes of this current study the statistical downscaling model SDSM was calibrated using 1961 to 1990 areal average daily precipitation totals for the Thames Region (see Section 3.3), and climate variables for the SE grid-box (Figure 4.5). Significant correlations were found between the daily precipitation amounts and several regional climate indices (near surface humidity, zonal airflow strength, vorticity, mean sea level pressure, and 850 hPa geopotential heights – a measure of the thickness of the atmosphere). Once calibrated, SDSM was then used to produce future estimates of the daily precipitation under Medium-High Emissions and Medium-Low Emissions scenarios.

Under both scenarios there is a slight increase in the number of winter rainfalls exceeding 12.5 mm/d by the 2080s, suggestive of greater flood risk by this time (Figure 5.4). Far more remarkable is the strong decline in the summer incidence of these events (which on average occurred just over twice per summer in the period 1961 to 1990). Under this scenario, the *frequency* of pollution events associated with the 'flushing' of combined sewer outflows (CSOs) would be expected to decline by the 2080s. However, this trend could be countered by an intensified heat island triggering more convective instability and localised thunder storms under marginal conditions (Atkinson, 1968). Furthermore, even with fewer events, the *polluting potential* from the flushing of CSOs could still be greater due to a combination of less diluted stronger sewage (due to lower summer infiltration to sewerage systems) and/or lower flows in the receiving water course(s). Wash-off pollutants, accumulated by impermeable surfaces such as roads during extended dry periods, could also adversely affect water quality.

Figure 5.4 Number of days in the Thames Region with winter (left column) and summer (right column) precipitation totals above 12.5 mm/d (Medium-High Emissions, and Medium-Low Emissions, downscaled), with respect to the 1961 to 1990 average



Longer-duration precipitation totals are also of interest following the October/November 2000 flooding (CEH and Meteorological Office, 2001). The annual rise in the 30- and 60-day duration autumn-winter totals is almost imperceptible under both the Medium-High Emissions and Medium-Low Emissions scenarios (Figure 5.5). However, beyond the 2050s, extreme precipitation events of 30- and 60-day duration do increase in magnitude (Table 5.6). For example, by the 2080s the 60-day precipitation event that occurs on average 1 in 10 years (i.e., probability 0.10) increases in magnitude by 10%, whereas the 1 in 20 year event (probability 0.05) increases by 16%. For both the 30- and 60-day events, the rarer the event (i.e., lower probability of occurrence) the greater the magnitude change. These results suggest that extreme precipitation events of the type experienced in late-2000 will become more common in the future – a result that is entirely consistent with UKCIP02 scenarios (Hulme et al., 2002).

Figure 5.5 **The 60-day duration autumn-winter maximum precipitation for the Thames Region (Medium-High Emissions, and Medium-Low Emissions, downscaled), with respect to the 1961 to 1990 average.**

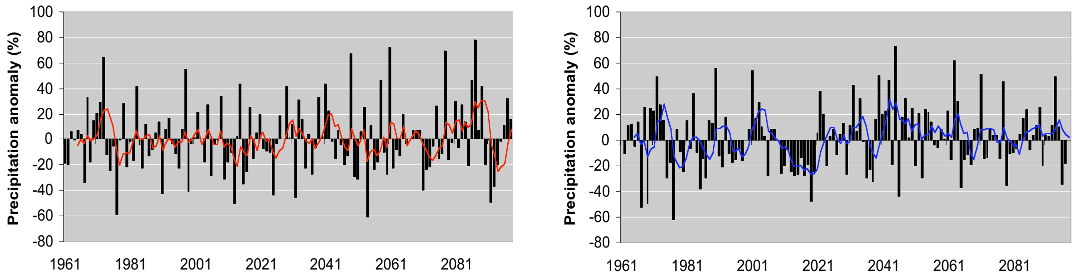


Table 5.6 **Percentage change in Thames Region 30- and 60-day duration autumn/winter maximum precipitation totals under the Medium-High Emissions scenario (downscaled)**

Scenario	Probability level (30-day event)			Probability level (60-day event)		
	0.5	**0.10**	**0.05**	**0.5**	**0.10**	**0.05**
2020s	-5	-6	+1	-4	+1	0
2050s	-5	-4	+10	-1	+11	+15
2080s	+4	+3	+8	-1	+10	+16

5.5.3 Urban Drainage Systems

Urban expansion over the last 200 years has resulted in the loss of several open rivers within central London such as the Fleet, Tyburn and Effra that now flow underground. A survey of the landscape status of London's river channels between 1992 and 1996 revealed that 29 per cent were natural, 56 per cent were artificially surfaced, and 15 per cent were culverted (EA, 2001b). This is of consequence, not only for the recreational assets of the City, but also for the rate and volume of runoff following excessive rainfall or snow melt (DETR, 2000a). In fact, a significant proportion of insurance claims are from non-riverine floods arising from intense rainfall events overwhelming urban drainage systems (ABI, 2002). The changes in future rainfall patterns shown in Figure 5.4, therefore, point to an increased likelihood of such flooding by the 2080s.

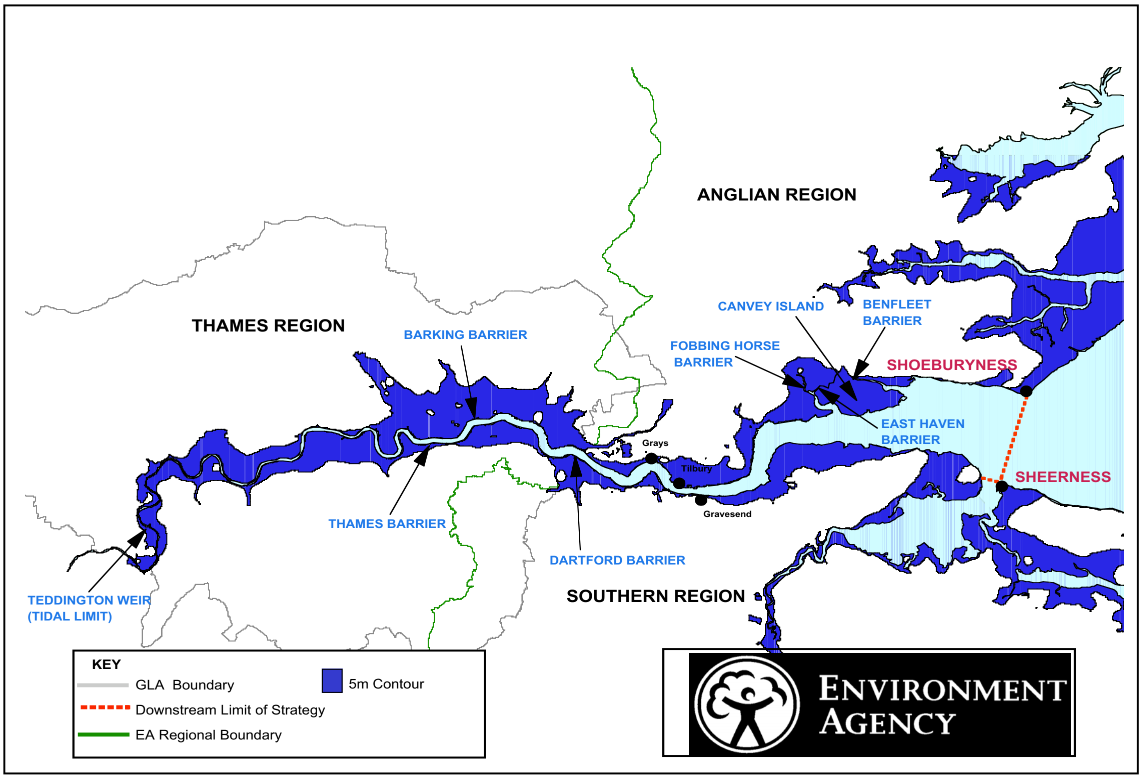
Research is currently underway to evaluate the performance of existing sewerage systems in relation to past patterns and future changes in rainfall event sequences and storm event profiles (UKWIR, 2002a). The project will also report on the significance of secondary factors in sewer system performance arising from groundwater infiltration, soil moisture deficits, and changes in water levels in receiving waters affecting sewer outfalls – all of which are potentially climate sensitive. For example, in catchments with significant groundwater contributions, enhanced winter re-charge and antecedent base flows will have implications for sewerage networks. Higher groundwater levels will mean that there will be both an increase of infiltration into sewer systems below ground level and in the ingress of surface water into sewers from above ground surface flow. The effects of both will be higher flows in sewers and associated pumping and treatment costs, and could potentially lead to increased incidents of sewer flooding from separate and combined systems. Climate change could also affect the capacity of receiving waters to assimilate discharges from sewer systems. For example, any increase in summer storms may cause combined sewer overflows to discharge pollutants into rivers which will have lower summer flows and thus reduced dilution capacity.

Sustainable Urban Drainage Systems (SUDS) are soft engineering facilities to help alleviate flooding associated with moderate rainfall events, involving the reduction of storm runoff volume (through 'peak-lopping') and increases to travel time of flood peaks to receiving water courses. For example, the restoration of natural wetlands in headwater catchments can provide source control of water derived from rainfall events as well as benefits to biodiversity. However, as with any drainage system SUDS have a capacity that can be exceeded given long duration events of the type experienced in the autumn of 2000 (see Table 5.6 and Figure 5.5), SUDS may be relatively cheap to install but can incur high maintenance costs and have limited operational life spans. There are also issues surrounding the legal ownership, maintenance and availability of appropriate sites for SUDS development in London given competing pressures to use brownfield sites for housing. The underlying London clay makes it difficult in some areas to use significant infiltration techniques.

5.5.4 Tidal Flood Risk

The potential implications of sea-level rise for Great Britain have been comprehensively reviewed by de la Vega-Leinert and Nicholls (2002). The most significant flood threat to London arises from tidal surges caused by low pressure systems travelling south or southwest over the North Sea, and the funnelling of water from the southern North Sea into the Thames Estuary (see Figure 5.6). The coastal flooding of 1953 resulted in over 300 fatalities in eastern England, but London was spared (Steers, 1953). Nonetheless, the event highlighted the potential threat to London, and resulted in a national flood defence strategy culminating with the completion of the Thames Barrier in 1983.

Figure 5.6 The area currently at risk from tidal flooding



Source: Planning For Flood Risk Management in the Thames Estuary, Environment Agency

The Thames Barrier and flood embankments provide protection for an estimated 1 million people against a 0.05% (or 1 in 2000 year) event currently, declining to 0.1% (or 1 in 1000 year) flood level by the year 2030. Thereafter, if improvements are not made the defence standard will continue to decline as a consequence of geological subsidence, natural climate variability and anthropogenic sea level rise (see Sections 3.8 and 4.3). By the 2050s, a 34 cm rise in sea level at Sheerness changes the 1 in 1000 year level, to a 1 in 200 year event (Wade et al., 2001). By 2100, it is estimated that the Thames Barrier will need to close about 200 times per year to protect London from tidal flooding (EA, 2001b). Future flood defence needs of London are, therefore, currently being reviewed by the Environment Agency, and will take into account increased peak flows in the Thames, sea level rise (natural and anthropogenic), and local changes to tidal conditions (Figure 5.6).

Rising sea levels and changes to the flow of the River Thames have potential consequences for the fine-grained sediment budget of the Thames Estuary system. Eroding cliffs at Sheppey currently provide 4.5 x 10^5 tonnes per annum of sediment, compared with an estimated 7 x 10^5 tonnes per annum fluvial supply from the Thames (Nicholls et al., 2000). The sinks for this sediment are unclear, but it is likely that the material is important to marsh development. Projected sea level rises are expected to increase rates of cliff erosion and supply of fine-grains to the regional sediment budget. The associated accretion in the estuaries and marshes could provide beneficial negative feedbacks to sea level rise in terms of flood defence. This is because a seawall fronted by 80 metres of saltmarsh need only be 3 m high (at a cost of £400/m), compared with a seawall without fronting/saltmarsh which may need to be 12 m high (costing £5000/m) (EA, 1996). However, successful recreation of intertidal habitats and added defence value requires a wider appreciation of coast cell functioning and sediment exchanges within the entire Thames Estuary system, plus wider North Sea. In other words, soft engineering solutions to rising sea levels involve a perspective that transcends the traditional limits of local administrative boundaries.

5.5.5 Stakeholder Concerns

In addition to the issues raised above, stakeholder engagement highlighted further potential flood risks related to climate change (Table 5.7).

Table 5.7 Potential flood impacts and responses identified by stakeholders

Associated Impacts
• Threat to Thames Gateway developments east of the Thames Barrier
• Greater public and corporate awareness of flood risk
• Loss of freshwater/riparian habitats (see below)
• Saline intrusion further up estuary and into adjacent freshwater marshland
• Greater demands placed upon emergency services
• Impact on existing floodplain landfill sites and loss of potential landfill sites
• Improved design and flood protection for new developments
• Mortgage and insurance difficulties leading to blighting of some communities
• Flooding of the London Underground (already being pumped)
• Greater threat to riverside developments and inundation of major assets such as sewage treatment works
• Access and aesthetics impaired by raised flood defences
• More foul water flooding
• Severe disruption to utilities and transport systems
• Intangible costs to the environment, recreation, and stress to flood victims

5.5.6 Adaptation Options

First order adaptation costs for future coastal flooding and storm risks have recently been produced by ERM(DETR, 2000b). The range of adaptation measures considered in this study included: accelerated investment in existing flood defence programmes; improved floodrisk identification, forecasting and awareness; and avoidance of at risk areas by new developments (or ensure adequate protection is in place). Other options include: low cost, ‘no regret’ measures such as improved flood warning systems; long-term planning for managed realignment (the discrete readjustment of existing defences to new proposed lines of defence located further inland); promotion of flood-proofing, building materials and design; the use/restoration of natural ecosystem buffers and floodplains (Bray et al., 1997; de la Vega-Leinert and Nicholls, 2002; Klein et al., 2001; Wade et al., 2001). Finally, increased collaboration between governmental bodies and insurance companies could provide an economic impetus to the planning of sustainable developments in the floodplain (ABI, 2002).

5.6 Biodiversity

5.6.1 Context

Global ecosystems are already subject to many human-induced pressures such as land-use change, pollution, loss of wildlife habitat, population change and resource demands (Vitousek et al., 1997). Global biodiversity is expected to decrease as a consequence of the continued destruction of natural habitats and increased land-use intensity (Heywood and Watson 1996). The introduction of exotic species and the differential effects of climate and/or chemical changes on species reproduction, dominance and survival may also be important at the global scale. For example, increases in nitrogen deposition and atmospheric CO_2 concentrations or new disturbance regimes may favour invasive species (Dukes and Mooney, 1999). Other studies suggest that northern temperate ecosystems will experience least biodiversity change because major land-use change has already occurred (Sala et al., 2000).

Climate change represents a further pressure that could change ecosystem functioning, spatial distribution and species composition (through changes in sea level, biological interactions, atmospheric composition, and disturbance regimes such as floods, droughts, frequency of fire, etc.) (McCarty, 2001). Climate change may also affect limiting factors and hence the ecological niche(s) of some species, both directly (as in the case of tolerable thermal ranges), or indirectly (as in soil nutrient cycling) (Schimel et al., 1991). For example, many different taxa around the world are already displaying poleward and elevational range shifts in response to key physiological controls such as temperature, moisture and length of growing season (e.g., Parmesan et al., 1999; 2000; Thomas and Lennon, 1999). Conversely, ecosystems exert significant controls over global water and carbon cycling – for example, terrestrial ecosystems may be net sinks for atmospheric carbon, even after losses due to land-use change are taken into account (IPCC, 2001b). The effects of climate change may also display long lag times as existing species survive but no longer reproduce.

Greater London covers nearly 158,000 ha of which two thirds is occupied by green open space and water, and nearly a fifth is considered valuable wildlife habitat (see Table 3.2). These green spaces support over 1500 species of flowering plant, and 300 types of bird have visited the City in recent years. As noted in Section 3.11, there are also a large number of nature conservation designations in London, and several nationally rare species of plants and animal. The London Biodiversity Partnership (2002) has prepared Species Action Plans (SAPs) for species regarded as special to London (bats, water vole, grey heron, peregrine, sand martins, black redstart, house sparrow, stag beetle, tower mustard, and mistletoe). A first round of Habitat Action Plans (HAPs) were also prepared for priority habitats identified by the UK Biodiversity Steering Group. This preliminary round included woodland, chalk grassland, heathland and wasteland. In addition, several other species and issues for discussion were covered by Statements, for example, the significance of exotic species to the cultural heritage of London, or the importance of private gardens (e.g., http://www.lbp.org.uk/action/statements/hsgardens.htm).

For the purpose of this report, it is convenient to group climate-related changes in London's biodiversity by the following major environments: 1) freshwater (including wetlands), 2) intertidal (including estuarine), and 3) terrestrial (including gardens). As previously indicated, current threats to biodiversity include loss of wildlife habitat to redevelopment, lack of, or inappropriate management (such as tree-planting) (Table 3.3). The following sections highlight factors that are directly and indirectly *climate* sensitive, such as loss of ecological niche(s), invasion by exotic species, incidence of disease and pests, air and water pollution, sea-level rise, impacts of changing river flow regimes, and summer drought stress.

5.6.2 Freshwater Habitats

Freshwater habitats – renowned for their high biodiversity and endemism – include lakes, permanent and temporary ponds, ephemeral streams, rivers, canals, and wetlands. The most important potential climate change impacts on lakes and streams include warming of waters (Webb, 1996); absence of shorter periods of ice cover (Magnuson et al, 2000); reduced summer flows and dilution of nutrients (Wilby et al., 1998); changes in physical habitat availability (Keleher and Rahel, 1996); changes in biogeochemical cycles including the mobilisation of heavy metals and pesticides (Schindler, 1997); increased primary production, eutrophic conditions, and oxygen depletion (Hassan et al., 1998). The importance of river corridors and wetlands to nature conservation across London is evident from their association with Sites of Special Scientific Interest (SSSIs) (EA, 2001b). For instance, the London Wetland Centre gained national recognition for its value to wildlife, having been designated a SSSI just 6 years after restoration work began on the site. Local Environment Agency Plans (LEAPs) provide a further framework for the integrated management of river catchments by, for example, enhancing marshland habitats created by new flood defence projects.

Changes in river flow regimes, water temperature and water quality can affect the survival, spawning times, reproductive success and growth of invertebrates, freshwater fish and amphibians (Beebee, 1995; Cowx, 2000). For example, the proportion of salmon migrating upstream in summer may be very low if the summer is dry – noticeable declines were evident in the droughts of 1989 and 1995 for instance. This pattern of behaviour may, however, be reversed if the flows are dominated by groundwater contributions (George, 1999). Given the slight decreases in summer flows from clay and urban catchments projected by Davis (2001), coupled with possible water quality changes, the outlook for the Thames salmon population is suggestive of further long-term decline. In some regulated rivers, however, there may be opportunities to maintain physical habitats by controlled releases from reservoirs.

London's wetlands are of ecological significance to a variety of plant communities, birds, amphibians and invertebrates (Table 3.3). Nationally, these habitats are under threat from altered flood regimes, drainage, groundwater abstraction, and development, in addition to global climate change (Dawson et al., 2001). Their vulnerability arises from the delicate balance between seasonal evapotranspiration, surface inflows and outflows of water, soil moisture, and groundwater discharges – changes to any one of these components can seriously impact the wetland. Following implementation of Water Level Management Plans (WLMPs), however, the Agency has been able to alleviate the effects of abstraction on a number of rivers and wetlands. For example, by redirecting a spring and installing water control devices at Ingrebourne Marshes, background water levels have been increased along with periodic flooding of the site. This has led to a dramatic improvement in the diversity of bird life and growth of reed and sedge (EA, 2001a).

The most important hydrological controls on wetland plant communities appear to be the mean, highest and lowest groundwater levels, together with inundation during the growing season (Wheeler, 1999). Moisture availability is critical to other habitats too. For example, by using the SPECIES model and simple water balance estimates for the future, the MONARCH study showed a drying of heathland and progressive loss of climate range for the shallow-rooted beech in southeast England under the UKCIP98 High scenario by the 2050s (Dawson et al., 2001). This is entirely consistent with observed high percentages of poorly foliated beech trees in years following the dry summers of 1987, 1989-1992, 1995 and 1997 (Cannell and Sparks, 1999). The 1995 drought stress has also been linked to an increase of deeper-rooted plants on grasslands (Buckland, 1997). This highlights a danger of extrapolating regional modelling to local impacts: the site-specific response of London's 273 ha of fragmented wetland is ultimately governed by the water level requirements of individual species as well as local water balance changes.

5.6.3 Intertidal Habitats

Situated at the highly dynamic interface between land and sea, intertidal zones are some of the world's most diverse and productive environments. The lower Tidal Thames is no exception, supporting as it does about 120 species of fish, 350 freshwater, estuarine and marine macro-invertebrate species, and nearly 300,000 over-wintering water birds (EA, 2001b). Areas of intertidal habitat are present along the entire length of the Tidal Thames, but the most extensive reaches are below Tower Bridge where the flood defences are set further back from the main channel (London Biodiversity Partnership, 2002). Other habitats, such as the reedbeds at Barking Creek have become re-established following the curtailment of dredging. The Thames estuary also provides a wide range of habitats such as shingle and mudflats, and salt marsh.

The biodiversity potential of the intertidal habitat largely depends on the local design, building materials and positioning of flood defences. Where the defences comprise sloping revetments there are opportunities for the establishment of saltmarsh (e.g., downstream of Tower Bridge); where the river is constrained by vertical concrete and metal piled walls, only a narrow fringe of foreshore is exposed at low tide (e.g., between Wandsworth Bridge and the Greenwich Peninsula). Under the latter circumstances, there are limited opportunities for vertical succession in the relative absence of 'natural' river banks. The Environment Agency is particularly concerned about further encroachment of riverside development on the Thames foreshore, and has suggested that unitary development plans for the London Boroughs adjoining the River Thames should include policies prohibiting development on the foreshore (EA, 2001b). The Agency is also seeking to protect river corridors and to enhance their ecological value through the planning process and best practice riverbank schemes. For example, at the Millennium site, Greenwich, the tidal defences were installed 130 m inland to create an additional 10 m of intertidal habitat, as well as an area of salt marsh with a series of terraces between the site and existing flood wall (EA, 2001b). Similarly, the recently announced reprieve from development for the western edge of the Rainham Marsh SSSI (FoE, 2002) is consistent with the wider objective of regeneration for the Thames Gateway zone, including riverside habitats.

The anticipated impacts of climate change and sea-level rise for London's intertidal habitat include increased levels of inundation and storm flooding; accelerated coastal erosion; sea water intrusion into freshwater tributaries; changes to the tidal prism, tidal range, sediment supply and rates of accretion; changes in air temperature and rainfall affecting growth of salt marsh plants with secondary effects on sedimentation (Adam, 2002; Kennish, 2002; Moore, 1999; Nicholls et al., 1999; Reed, 1990). One of the most significant threats to the biodiversity of the intertidal habitat is currently the flushing of storm sewage from London's Victorian sewers during intense summer storms (Section 3.5.2). However, intense rainfall events are projected to become *less* frequent in summer (but more frequent in winter) under the UKCIP02 scenarios. The net effect on biodiversity will depend on a host of related factors such as the volume of summer flow in receiving watercourses and rates of groundwater ingress to the sewerage network.

Although the MONARCH project did not explicitly consider intertidal habitats, the impacts of the UKCIP98 climate change scenarios on estuarine waterbirds and coastal geomorphology were assessed (Austin et al., 2001). Climate change was shown to affect Britain's over-wintering waterbird population in two main ways: firstly, through the *direct* effect of changes in (severe) weather on waterbird distributions and their invertebrate prey; second, through the *indirect* effect of rising sea levels on the availability and nature of coastal habitats. For example, projected increases in rainfall and gale-force winds under the UKCIP98 Medium-high scenario would be expected to harm wader populations by decreasing food intake (Goss-Custard et al., 1977). Managed realignment of Thames-side coastal defences may result in more extensive mudflats at the expense of salt marshes, improving habitat availability for the oystercatcher but reducing it for the redshank and dunlin.

As indicated previously, changes in estuary morphology depend on regional sources and sinks of fine-grained sediments (Section 5.5.4), as well as on the local history of land claimed from the sea. Natural features such as salt marshes can absorb wind and wave energy, retarding some of the effects of sea level rise, and contributing to the natural resilience of the system (King and Lester, 1995). However, the response of tidal marshes to sea-level rise depends on a host of local factors. Marshes located between coastal defences and rising sea levels may be subject to 'coastal squeeze' (i.e., progressive loss and inundation) if the tidal foreshore is lost to solid encroachments (Nicholls and Branson, 1998). Conversely, if the backshore slope is low enough or unimpeded by infrastructure, and there is sufficient sediment for accretion, the foreshore/wetland may expand landward (Brinson et al., 1995).

5.6.4 Terrestrial Habitats

The London Biodiversity Audit covered a wide range of terrestrial habitats (e.g., woodland, open landscapes, grasslands, meadows, heathland, cemeteries, urban wasteland, farmland, etc.; see Table 3.3). The most extensive natural habitats in London are unimproved and semi-improved neutral grassland, followed by woodland. The gardens and parks of London also represent a particularly important ecological resource for flora and fauna, with a combined area of approximately 20% of Greater London. Although gardens are heavily managed, climate is still a significant driving mechanism governing the potential ranges of species, timing of life-cycles (phenology), physiology, and behaviour. Furthermore, garden plants are susceptible to damage from extreme winter frosts, late spring frosts, summer drought and localised winter waterlogging (Burroughs, 2002), as well as from weather-related garden pests and disease (Hardwick, 2002).

Earlier springs, longer frost-free seasons, and reduced snowfall in southeast England (Sections 3.2 and 3.3) have affected the dates of emergence, first flowering and health of leafing or flowering plants (Sparks and Smithers, 2002). For example, warmer temperatures in early spring are associated with earlier dates of oak leafing at Ashted, Surrey, by about 6 days for each 1ºC increase (Sparks, 1999). This suggests that climate change will produce more first leafing dates in March unless other controls on leafing prevail. Tree *health* is more a function of air pollution concentrations (Ashmore et al., 1985;) and water stress, with major reductions in the crown density of beech coinciding with droughts in southern Britain (Cannell and Sparks, 1999). Natural woodlands suffering from drier summer conditions in the future may become more susceptible to insect pests, disease and windthrow during the stormier winter conditions. However, drought stress during summer can also afford protection from ozone damage by enforcing stomatal narrowing or closure (Zierl, 2002). Conversely, grass productivity is substantially reduced during hotter, drier summers (Sparks and Potts, 1999), pointing to increased water demand for lawn irrigation under the UKCIP02 scenarios.

Bird populations are sensitive to many types of environmental change and, because they occupy a position at or near the top of the food-chain, give indications of overall ecosystem functioning. For example, the recent increase in grey heron numbers in London has been attributed to the improvement in water quality (leading to higher natural fish populations) and the absence of severe winters (Marchant et al., 1990). Small birds, like the wren, are particularly prone to prolonged spells of cold, wet or snowy weather, and therefore provide an excellent index of very cold winters. Records of the wren population on farmland and woodland since 1962 are strongly related to mean winter temperatures in central England, and have maintained relatively high numbers since the 1990s (Crick, 1999). Similarly, annual variations in the first laying dates are often strongly correlated with variations in spring temperatures (Crick et al., 1997), but mismatches in the timing of laying relative to food supplies can reduce bird populations (Visser, 1998). Changes in migratory patterns and arrival dates have also been noted but this will depend on the specific trigger(s) for migration. For example, a 1ºC increase in spring temperature is associated with a 2-3 day earlier appearance of the swallow in the UK (Sparks and Loxton, 2001).

Thus, climate change has the potential to affect future bird migration, winter survival, and egg-laying. The MONARCH project assessed the impacts of six bioclimatic variables on the distribution of ten breeding birds at 10 x 10 km resolution under the UKCIP98 Low and High scenarios by the 2020s and 2050s (Berry et al., 2001). (Habitat, however, was not included in the training of the model and the ten birds studied are not all appropriate to London's avifauna). Under the High scenario the most significant reductions in southeast England climate space occur for the willow tit, nuthatch and nightingale, due to warmer and drier conditions affecting woodlands and insects. Since woodland is the second most extensive natural habitat of London, these reductions could be reflected in the range of birds visiting the back gardens of suburban London. Conversely, the potential distribution of the reed warbler increases nationally, along with the yellow wagtail and turtle dove (which is contrary to the current decline in the latter two), probably reflecting an affinity for a warmer, drier climate. These results should, however, be treated with caution because the science underlying the MONARCH assumptions is less than complete.

Insect distributions and the timing of insect activity are also highly weather dependent (Burt, 2002). For example, the ranges of butterflies in North America and Europe have shifted poleward in response to rising temperatures (Parmesan, 1999). Extensive records of insects throughout Britain since the 1960s and 1970s indicate that a 1ºC increase in temperature is associated with a 16-day advancement in the first appearance of the peach-potato aphid, a 6-day advance in peak flight time of the orange tip butterfly, and an 8-day advancement in the time of activity of the common footman moth (Sparks and Woiwod, 1999). Finally, it is recognised that climate plays a dominant role in vector-borne diseases – directly through its effects on insect development, and indirectly through its effects on host plants and animals. Although it has been suggested that the most lethal form of malaria can not be transmitted by mosquitoes in the UK

(Marchant et al., 1998), the number of cases of Lyme disease spread by ticks has approximately doubled in the UK since 1986 (Subak, 1999). Higher year-round temperatures in the future are likely to increase the risk of recreational exposure to Lyme disease, changes in tick numbers and activity.

Finally, London is home to numerous flora and fauna introduced from warmer parts of the world but now flourishing in the City. Many exotic species have been inadvertently introduced via imported materials such as foodstuffs, timber, minerals and birdseed. Others have 'escaped' from gardens to be naturalised (e.g., butterfly bush, michaelmas daisy, Japanese knotweed) or have formed spontaneous hybrids with their native relatives (e.g., Highclere holly, Spanish bluebell). The rich cultural botany that has developed around areas such as Deptford has become part of the local heritage. Part of this success has been attributed to the favourable climate of London's heat island (see Sections 3.2 and 5.2). Longer growing seasons, reduced incidence of night frosts and higher maximum temperatures in summer have allowed plants such as London rocket, Guernsey fleabane, hoary mustard and Chinese mugwort to thrive (see: http://www.lbp.org.uk/action/statements/ssexoticflora.htm). Projected increases in regional temperatures under the UKCIP02 scenarios together with possible intensification of the heat island will allow such flora, along with naturalised bird species (e.g., collared dove and ring-necked parakeet) to thrive in the future. However, the same conditions could also favour a small minority of introduced plants that cause significant problems in London's ponds and canals (e.g., New Zealand pigmyweed, parrot's-feather, floating pennywort), and terrestrial habitats (e.g., Japanese knotweed, giant hogweed).

5.6.5 Stakeholder Concerns

In addition to the issues raised above, stakeholder engagement highlighted further potential biodiversity impacts related to climate change (Table 5.8).

Table 5.8 Potential biodiversity impacts and adaptations identified by stakeholders

Associated Impacts
• Increased tourism and leisure pressure at conservation sites
• Increased soil erosion associated with more intense winter rainfall
• Increased expenditure on pest control
• Air quality impacts from incinerators, water quality impacts from landfill
• Use of building roofs for green space and water storage
• Restricted access to sensitive sites and habits (e.g., foreshore)
• Use of green spaces and river corridors to allow species to move to new climate space(s)
• Greater public education and involvement in 'biodiversity networks' (phonology)
• Greater recognition of dynamic ecosystems in site designation and management

5.6.6 Adaptation Options

The ability of ecosystems to adapt to the direct effects of climate change is largely a function of genetic diversity and the rate of change (IPCC, 2001b). A growing body of evidence suggests that climate change should be treated as a current, not just a future, threat to species (Hughes, 2000; McCarty, 2001). However, humans may intervene in the processes through a range of conservation methods. One approach to protect declining wildlife and plant populations is to establish reserves or designated areas. Unfortunately, the Institute of Terrestrial Ecology, estimate that 10% of all UK nature reserves could be lost within 30-40 years, and that species distributions could change significantly in 50% of designated areas in the same period (DETR, 1999). Moreover, nearly all land suitable for designation is already protected, and some habitats are relatively well protected compared with others (e.g., the distribution of SSSIs largely reflects endangered plants).

A further difficulty involves reconciling the disparity between the current distribution of reserves and future distributions of species due to climate forcing (e.g., due to coastal squeeze). In this respect London's 'green corridors', such as river corridors and railway lines, may be important for species migration, and should be protected (EA, 2001a). Another solution may be for planners to recognise biodiversity hotspots (Myers et al., 2000) – areas containing concentrations of endemic species facing extraordinary threats of habitat destruction (IPCC, 2001b). Under such a scheme, a wetland threatened by summer water-level drawdown would figure explicitly in regional water resource strategies. Such activities might fall within a wider remit of habitat restoration (Petts and Calow, 1996). Other options include captive breeding and translocation programmes for endangered species, but no techniques currently exist for translocating intact biological communities (even space permitting).

Area designations and planning controls should also be considered within the wider context of environmental improvement, recognising that fully pristine habitats are non-existent. For example, many aquatic species are sensitive to changes in river flow and associated water quality. Although chemical General Quality Assessment (GQA) has improved in recent years, the biological quality of London's rivers and of the tidal Thames continues to be variable as a consequence of rainfall fluctuations affecting urban runoff and effluent quality (EA, 2001b). In such circumstances, adapting to changes in climate might involve the introduction of new water treatment technologies for more stringent quality standards (as part of the work already being undertaken on Combined Sewer Outfalls (CSOs) under the AMP3 process). However, the benefits of more stringent effluent treatment should be weighed against associated increases in greenhouse gases (Colquhoun, *pers. comm.*), to evaluate the net environmental impact. Treatment of diffuse pollution sources arising from agricultural areas beyond London, could be addressed through raised awareness, and the establishment of riparian buffer zones along river corridors (Wade, 2001). Similarly, an appreciation of the complex (transdisciplinary) processes involved can lead to environmental enhancement in the face of change. For instance, effective coastal defence and habitat conservation can be accomplished through soft engineering measures that acknowledge the strong link between geomorphic and ecological processes (Lee, 2000).

5.7 Summary

The above sections provide an assessment of the most significant potential climate change affects on London's environment, identified through literature review, stakeholder consultation, and impacts modelling. The key issues are summarised in Table 5.9. These themes provide the basis for subsequent discussions of societal and economic impacts: the mandate of the two remaining work streams.

Table 5.9 Summary of key climate change impacts on London's environment

Issues	Climate variables	Potential impacts
Urban heat island	• Nocturnal temperatures • High pressure and low wind speeds • Dominant airflow direction	• Increased summer heat stress and mortality • Reduced winter space-heating • Higher underground temperatures • Increased use of air conditioning • Increased risk of fires • Higher rates of refuse decay • Increased water demand
Air quality	• Stagnant summer anticyclones • Airflow direction • Temperature inversions • Catalysing sunshine • Thunderstorms	• Increased concentrations of ozone, VOCs, SO_2, particulates and pollen • Acute asthma epidemics • Deleterious effects on urban trees and urban fabric • Export of pollutants to wider region
Water resources	• Winter and summer precipitation • Potential and actual evaporation • Soil moisture	• Reduced summer soil moisture • Shorter potential recharge season for aquifers • Lower summer flows • Higher winter flows • Deteriorating water quality • More leakage due to clay shrinkage/expansion • Increased domestic water demand • Use of rising groundwater • More conflict between environmental/societal demands
Flood risk	• Seasonal precipitation totals • Winter soil moisture • Heavy daily precipitation • Multi-day precipitation totals • Snowmelt • Sea level rise	• More heavy precipitation days in winter • Fewer heavy precipitation days in summer • Heavier multi-day precipitation totals in winter • More frequent flooding of underground network • More localised shallow groundwater flooding • More frequent closures of the Thames Barrier • Increased supply of fine-grain sediments • Saline intrusion to freshwaters

Issues	Climate variables	Potential impacts
Biodiversity	• Summer drought/low flows • Spring temperatures • Soil and groundwater levels • Air quality • Water quality and temperature • Sea level rise • Storminess, wave heights • Disturbance regimes e.g., wind throw and fire	• Changes in physical habitat availability • Increased primary production • Changes in species phenology, physiology, behaviour, health, reproductive success and community structure • Coastal squeeze of Thames estuary intertidal habitats • Increased coastal and salt marsh erosion • Increase accretion in estuary • Extended range of some exotic species • More pressure from tourism at conservation sites • More conflict between societal/environmental needs

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6. The Potential Social Impacts of Climate Change in London

6.1 Introduction

London is a large and complex city which has persisted as the dominant, and by far the largest, city within England, and more widely in the UK. For many hundreds of years over 10% of England's population have dwelt in London and its role in the national economy has always been pivotal, if sometimes controversial. Culturally, London is far more diverse than other UK cities, and has a higher percentage of Black and Minority Ethnic residents than anywhere else, at 27% of the population (compared to national average 7% and the next highest region at 10%). Arguably, social and cultural integration has advanced further in the capital than elsewhere. On average 4,550 people live in each square kilometre of London, over twice the population density found in most UK cities; within the European Union only Paris and Brussels are more densely populated. There are acute housing and office space shortage and rising housing and land costs. Large building programs are required to meet the latent and growing demand (500,000 houses over the next fifteen years) since Londoners are starting to live in smaller family units or by themselves: the number of households is growing at a faster rate than the population overall.

Nearly half of the Greater London workforce (48%) is classified as 'professional' or 'managerial and technical', compared to a national average of 38% in these two categories (ONS 2001). Per capita, Londoners also have higher incomes than elsewhere in the UK. (Compared to a UK average of 100, London's per capita GDP score is 128.5, whilst the North East is 83.9 and the West Midlands 91.8 for example) (ONS 2001). These higher-than-UK-average incomes, however, mask a very unequal distribution of incomes in London (GLA 2002a). The disparities in income are significantly higher in London than elsewhere in the UK, with unusually high incomes at the top end of the distribution and a greater proportion that the UK average in lower income brackets. One in five households have a weekly income of less than £150, in a city with the highest property prices in the UK (average property price £205,850). Five of the ten (and 13 of the 20) most deprived districts in England are in London. Unemployment is higher amongst the Black and Minority Ethnic than the white community (at 13.5% compared to 5.1%). The Bangladeshi community has a particularly high unemployment rate, followed by the Black African and Black Caribbean communities (LHC 2002).

Within this context, climate change will have both direct and indirect impacts on the social aspects of London life. We have used the following definition of 'social' and attempt in this section to bring discussion back to how these aspects of London life would be affected by climate change:

> *"overall health and well-being, social and economic equity, public safety, public health and infrastructure, civil cultural and political society (including political institutions), and who bears the costs and reaps the benefits in a future London."*

Most assessments of climate change in the literature have focussed on either the physical world, such as on biodiversity, or on the physical aspects of human systems such as crop production and water supply (e.g. ACACIA, 2000). This is because such impact areas are more readily quantified and numerical models and other techniques are available for assessment purposes. Social systems and behaviours are frequently more difficult to analyse using quantitative methods. There is a higher degree of subjective interpretation, for example in defining whether a community is 'vulnerable' or has a high capacity to adapt to climate change impacts. Unlike assessments of the environmental impacts of climate change, it is difficult to produce 'objective' numbers which give the 'right' answers in the social, political and cultural aspects of climate change impacts. Yet, many stakeholders in this study have expressed a strong interest in the social repercussions of climate change. We decided not to shy away from addressing these highly relevant issues even though the 'answers' will be more uncertain and subjective than those in Section 5 and depend upon what assumptions are made - about responses, for example. When feedbacks between social, economic and environmental impacts of climate change are addressed, one can see that even the assessment of the physical impacts of climate change is affected by social uncertainty.

In this 'Social Impacts' section of the report, we have used a ***scenario*** approach to address how climate change may affect social aspects of London. A scenario, or a picture of a potential future, is not a prediction but a vision of one possible way that the future may turn out. Using detailed descriptions of a possible future allows us to analyse what life would be like, and what the implications would be for every aspect of society. We are unable to predict exactly how the future will unfold, not least because *we have a choice as to how that future will look.* To a certain extent, the future social, economic and environmental aspects of London life are what we make them. This applies equally to climate change. The climate change scenarios presented in Section 4 consider two rates of emissions of greenhouse gases (Medium-Low and Medium High Emissions). The differences in climate between these are dependent on *socio-economic choices* we make as a society. It is therefore unrealistic to consider changing climate without also considering the social and economic circumstances which may bring those future climates about.

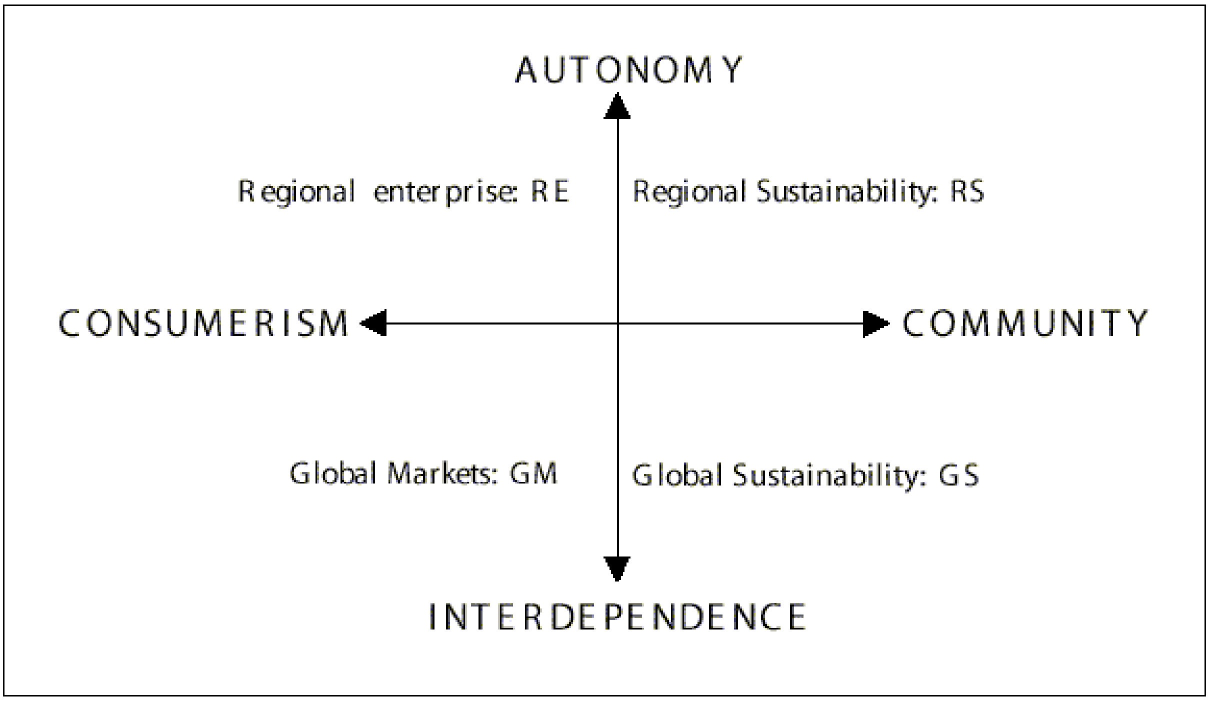
6.2 Combining Changes in Society with Changes in Climate: The Socio-Economic Scenarios

The climate change scenarios presented in Section 4 represent the consequences of many social and economic changes; the changed climate of 2050 will not occur in a world frozen in 2002 in every other way. All other aspects of London, UK and global society and economy will have moved 50 years into the future. We know that some things are likely to remain similar to today. For instance, many of the buildings and much of the infrastructure will be the same, unless some surprise event or disaster takes place, although cultural change could modify the way we view buildings and their desirable time-span. (In Tokyo it is common for modern buildings to be replaced after just 10 years: there is a very different attitude there than in London to the longevity of the urban landscape). The 'hardware' within which the city is lived will probably remain quite similar in many parts of the city, though major change could well be experienced in targeted redevelopment areas (e.g. parts of East London). London is defined to the external world through some of its principal monuments and sites (Tower Bridge, Trafalgar Square, Houses of Parliament, Westminster Abbey, St. Paul's Cathedral, Buckingham Palace, etc.) and it is highly likely that these will remain important reference points of London's identity through the next 50 years, just as they have been for the past 50 years (and much longer).

What is less certain is what will happen to the 'softer' emblems of London: double-decker buses, local markets, carnivals and festivals, local parks and heaths, to name but a few. What changes and what 'stays the same' is determined not simply by inexorable exogenous forces, therefore, but by social and political consensus on what represents London as a city and is important in formulating its internal and external identity.

As described in Section 4, the UKCIP02 climate change scenarios are based on a methodology for thinking forward 50 years developed by the Intergovernmental Panel on Climate Change (IPCC, 2000), the Foresight scenarios and their UKCIP derivatives. These provide conceptual and coherent descriptions of future social, economic and political-policy issues. The UKCIP scenarios framework has taken social and political values, and the nature of governance to be fundamental and independent determinants of future change. By examining a continuum scale between 'Autonomy' and 'Interdependence' and between 'Consumerism' and 'Community' the worldview and subsequent actions of future societies can be constructed. A version of the typology is shown in Figure 6.1 below (UKCIP 2001). The precise definition of the scenarios is tailored to the regional character of this study; this is possible because there is no single 'correct' definition (they are in the end social constructions which can be formulated in infinite ways).

Figure 6.1 The Adapted UKCIP Socio-Economic Scenarios



The IPCC has explicitly linked greenhouse gas emissions associated with similar socio-economic scenarios to climate change, providing an 'integrated' picture of how climate, society and economy may change (IPCC, 2000; 2001). Although these relate to the global scale, the links between the IPCC and the UK-based Foresight scenarios allow some interpretation at regional scales. The Global Markets (GM) and Regional Sustainability (RS) scenarios are worlds in which greenhouse gas emissions are equivalent to the UKCIP02 Medium-High and

Medium-Low Emissions levels respectively. We now present in more detail how these worlds would look.

6.2.1 Global Markets (GM)

This scenario could be described as 'Dynamics as usual' - very rapid economic growth, population peaks mid-century; globalisation of economic relations and, to some extent, socio-cultural forms; market mechanisms dominate, accompanied by public choice approaches within governance; reliance on fossil fuels. London continues to play key role as one of a handful of global centres of capital and trading, and continues to dominate the UK economy. There would be medium-**high greenhouse gas emissions** associated with this scenario, producing a correspondingly high level of climate change, e.g. London summer temperatures 3°C above 1961-90 average by the 2050s and 4.5°C above by the 2080s.

6.2.2 Regional Sustainability (RS)

In this scenario, there is a significant shift in London away from the pursuit of economic growth for its own sake, and a much greater emphasis on sustainability. Local solutions to local and global problems are sought and there is encouragement of 'green' technologies and lifestyles. London's population stabilises by 2010 and then starts to decline slightly. Policies are put in place to reduce inequality. There is a genuine attempt to reduce the ecological 'footprint' of London. There would be medium-**low greenhouse gas emissions** associated with this scenario, hence a 'medium-low' level of climate change, e.g. London summer temperatures 2.5°C above the 1961-90 average by the 2050s, and 3.5°C above by the 2080s.

6.2.3 Using the Scenarios

Why, then, have we chosen to examine these two scenarios in detail? Firstly, we decided on the basis of past experience, that examining all four scenarios was not practicable in the time available. Secondly, we reasoned that 'global markets' and 'regional enterprise' are rather similar scenarios in the London context, this being because London is already (along with Tokyo and New York) a regional site of the global marketplace. Thirdly, we decided that Regional Sustainability would be a more interesting, because it is a more challenging scenario to explore than Global Sustainability. This is because for a mega-city such as London to become sustainable on a regional basis is far more challenging than for it to do so globally (where its high population density could allow trade-off with lower population density areas).

Examples of issues which can be considered in the socio-economic scenarios are:

- Movement of people across and between countries, bringing with them fresh ideas, new cultures and skills;
- Change in incomes and wealth;
- Changes in lifestyle and values, in the environmental imperative, and in information technology will all have an effect;
- Change in opinion and values that mean many people are more or less willing to tolerate discrimination, the misuse of resources or pollution.

Table 6.1 suggests how each variable might change under each scenario based upon the authors' interpretation and the scenarios literature (e.g. UKCIP 2001).

Table 6.1 Key Features of the Global Markets and Regional Sustainability Scenarios

Variable	Global Markets	Regional Sustainability
International Migration	High, driven by economic demand for more employees.	Low since the aim is to make each region more sustainable and self-sufficient. Rather than people moving, the objective is to improve standards of living elsewhere.
Change in incomes & wealth	Greater disparity in incomes emerge due to market forces. Ranks of super rich and super poor grow.	Drive to reduce disparities in income and wealth. Assistance provided for lower-income workers to buy property, etc.
Change in lifestyle & values	Increasing choice of goods and services allow individuals to exercise personal lifestyle choice. High pressure jobs and long work patterns become more wide spread.	Tendency to prefer higher quality of life, time with family and friends, etc. to material goods and services. Companies provide more flexible work packages, allowing time out, community-volunteering, etc.
Change in perceptions & beliefs	Individual choice remains dominant; strong confidence in science and technology to find solutions to emergent problems. Equality of opportunity.	Family and community-oriented values see an upsurge. Environmental beliefs become more widespread; lack of environmental concern becomes less socially acceptable. Equality of outcomes.
Change in leisure and tourism	Increased globalised tourism & leisure, with much more and cheaper aviation. Older and younger population much more mobile. More international migration, hence associated travel.	More localised and UK or near-continent based tourism & leisure. Reduced aviation-based tourism. The idea of 'going on holiday' replaced by 'being on holiday' in your own locality.
Change in commerce	International business and commerce dominate. International financing of science and technology, which drives the global economy.	Move away from global trade to local and regional economic development. Encouragement of SMEs serving local needs. Science and technology become more localised, slowing down pace of change.
Change in industry	'Old manufacturing' declines, whilst high-tech. manufacturing grows; job insecurity rises	Old skills in manufacturing re-activated by need to supply local needs; return to improved job security
Change in transport	More premium-payment transport solutions provided, e.g. high fares upon privately financed transport links. This increases unequal mobility.	Strong emphasis on community-based, low-priced, heavily-subsidised transport solutions, with high charges for private car users and for aviation.
Change in health care	Trend is towards more privately-based and financed health care, e.g. through private insurance measures	Re-invigoration of the public health care sector.
Attitude to environment	Environment to be used to further economic growth. Must be protected if growth is threatened, and it is economically viable to do so. 'Conquer nature'	Environment is valuable for its own sake. Less easily-quantified considerations such as amenity value are taken into account in development decisions. 'Work with nature'
Change in arts & media	Media consolidates further at the global scale, with more concentration in fewer hands; rapid expansion in 'pay as you go' multi-media options, e.g. cable, satellite, mobile communications	Prevention of excessive concentration of the media. Encouragement of local to regional media and community-based multi-media.

Variable	Global Markets	Regional Sustainability
Change in Communities	Greater number of individual households. Generally increased fragmentation of spatially-based communities. People's social relations defined more through workplace, internet, leisure activities, etc.	Move towards community-focused living. Reverse of trend towards single-occupancy households. 'Extended families' start living closer to each other once again across society. More time and opportunities available to facilitate social interaction in neighbourhoods.
Change in policing & community safety	High-technology, remote-sensing policing in which a highly trained, relatively small police force controls London via CCTV and associated, more powerful, future technologies.	More community control over policing. CCTV and remote-surveillance technologies are phased out.

Source: authors and drawing upon UKCIP (2001), IPCC (2000)

In our workshop application of the GM and RS scenarios (see Appendix B: Study Methodology), we found a proclivity to brand GM as 'bad' and RS as 'good'. We suspect that this is because GM is a more familiar prospect to the participants, representing more closely the present situation. Hence the 'bad' side of the scenario are more immediately evident, whereas the 'bad' aspects of the RS scenario are less apparent. The RS scenario does, however, entail a major shift away from the global financial and business service role that London currently depends upon for much of its economic wellbeing. A decline in this could have major and far-reaching economic ramifications for the city and, to be accepted, might require a quite radical change in values away from economic and financial incentives and current indicators. If there was widespread acceptance that time with family and friends or engagement in community activities that required little if any expenditure, were much more important than financial or work achievements, then the RS scenario would be achievable. This, however, is a very significant social and value-shift and there is very mixed evidence of it occurring in practice. (We are not suggesting that many people do not already make this decision; the important aspect we allude to in RS is the change or shift in lifestyles from the present, so that emphasis on community becomes the norm).

There is also uncertainty about what an RS world would actually be like to live and work in and a risk that it would not be economically sustainable or that it would be considered widely undesirable, given the cultural shift towards individualism in the western world. However, that is not to say that society in the future would not choose such a path. A further limitation of the RS scenario with respect to its implied carbon emissions (hence low level of climate change) is that it assumes that regional sustainability occurs through out the world in an analogous way to what occurs in London. If that is not the case, then carbon emissions might be very high in other parts of the world because of the occurrence of rapid economic growth. In that case, carbon emissions and global climate change rates would be higher and London would have to face an RS world in a context of high climate change. We will allude to the particular problems this anomaly could create throughout the document. (The analogous case, where a GM world is combined with a lower level of climate change, should not produce any problems not already faced by a GM/high climate change world: indeed the impacts of climate change would generally be alleviated).

Finally, we fully acknowledge the limitations of utilising only two socio-economic scenarios here. Inevitably, we cannot capture the full complexity of socio-economic and political dynamics and some futures are less readily expressed in the current structure than others. For instance, approaches for sustainable development which rely heavily upon market mechanisms (natural and socially-responsible capitalism) are less readily accommodated in the scenarios framework. Development of desirable 'end-point' scenarios by the London Climate Change Partnership itself might be a useful step in future work on adaptation.

6.3 The Draft London Plan: A Hybrid Scenario?

The draft London Plan in effect presents its own scenario for London, but on the much shorter time scale of the next 15 years. How, then, does the draft London Plan scenario relate to the Global Markets and Regional Sustainability scenarios? We could perhaps identify the draft London Plan as a hybrid scenario containing elements of GM and RS. There is undeniably an emphasis on preserving, and if possible enhancing, London's global role as a financial and business services centre. The influx of new inhabitants is welcomed as a way of satisfying the labour shortages, with 600,000 new jobs anticipated. The view is taken that the choice that will be made by global companies is not 'London versus other British cities', but 'London versus New York, Tokyo, Paris or Berlin'. This identification of London as the jewel in the crown of the UK economy, is very much a continuation of its traditional role in the UK, hence 'dynamics as usual'. At the same time, the Plan recognises the considerable social and economic disparities within the city and the need for more sustainable approaches. Hence, there is a strong emphasis upon community development and policing, better health care and education, more effective and equitable transport, a solution to the problem of overly-priced housing, more attention to the problem of over-crowding in houses in certain sections of society due to house prices, more sustainable building design, reduction of waste and more sustainable use of energy and enhancement of open and green spaces. These strategies and policies tend much more towards sustainability, with its focus on equity, balance between economic and social development, and limiting environmental impacts.

The draft London Plan scenario is in some respects similar to GM for some issues (e.g. economic growth, population change, new jobs), and similar to RS (or a global sustainability scenario) in others (e.g. sustainable design & construction, community development, policing, affordable housing, etc.). It is important to stress that the underlying basis for the draft London Plan scenario and the GM and RS scenarios is different in several important respects. Firstly, the draft London Plan projections to 2016 are based upon established forecasting methods, such as econometric models. The GM and RS refer to 50 years hence, and there is no known forecasting method or model able to reliably capture socio-economic, political or cultural change on such long timescales. Hence, our scenarios are deliberately qualitative, to avoid the false impression that they are anything other than indicative.

Secondly, the draft London Plan is a critical document to assist in detailed planning and policy decisions which have to be taken now and in the next several years. By contrast, the climate and socio-economic scenarios we use, operate at a much less refined level of detail and sophistication. To use an analogy, the draft London Plan is equivalent to planning your holiday in, say, 3 months times. Attempting to use the climate change and socio-economic scenarios in this way would be like trying to plan in detail a holiday to be held in 10 years time: what day you intend to leave, where you will stay over, which travel mode and firm you will use, and so on. The appropriate way of using the climate change and socio-economic scenarios is instead to obtain a broad-brush evaluation and assessment of policies and commitments being entered into in the near term. They can be seen as a 'check list' against which policies can be passed to explore how 'climate change (un)friendly' they are.

6.4 Need for a Comparative Approach

The consequences of climate change in any one place are inextricably linked-up with climate change impacts elsewhere. This is because of the interconnectedness of the flows of people, money, resources, goods and services between different places. Hence, the potential impacts of climate change in London are intertwined to some extent with the possible impacts in other cities and regions. A comparative approach also has the advantage that it allows us an insight into what the future climate change of London might be like in tangible terms, i.e. compared to other present-day cities. Hence, by the 2050s London's summer extreme would perhaps be comparable with present-day Paris or Berlin, and to New York or Madrid by the 2080s. A further use of such comparisons is that they help to identify potential adaptation strategies, given that cities such as Madrid and New York already cope with temperatures anticipated to occur in London in the 2050s to 2080s.

As the draft London Plan makes clear, the particular bundle of skills, services and activities in the capital render it in many senses unique within the UK, so that the most appropriate comparison is not with other UK cities, but instead other global cities which provide competing services, in particular Tokyo and New York. Because Tokyo and New York are (to some extent at least) serving needs in Asia and America, we should caution against assuming that trade can readily be transferred between these cities. It might, therefore, be as useful to compare London to, say, Paris, Berlin, Frankfurt and Brussels. Furthermore, we know that business often depends upon long-established reputations and networks of knowledge and trust, and hence business is generally not quite as footloose as might be imagined, particularly high-value added work, where much of the skill is 'intangible' and hence not easily transferred.

A scenario approach also leads us to question the assumption that London would not face competition from other cities in the UK. If, for instance, there is a strong shift towards regional governance and devolution, then there could conceivably be a greater distribution of the finance, business services, media, arts and culture activities, etc., currently concentrated in London. The model for this is, perhaps, Germany, where Hamburg is lead city for media and publishing, Frankfurt for finance, Berlin for administration, arts and culture, Munich for the automobile industry, and so on. Germany shows that it is not impossible for such regional distinctions which are globally competitive to emerge within a single nation. Even if we do not accept the importance of the devolution and regionalisation agenda for London, a scenario approach is still very helpful in providing a wider range of possible medium- and long-term futures.

The growth projections in the draft London Plan appear to be based on the very high growth rates that London experienced in the 1990s. Assumptions about continued high economic growth are also not at all guaranteed, merely because in the long-term past such growth has always happened. As global inter-connectedness increases, the systems created to run our countries and economies become ever more complicated. They may appear to become more 'solid' as they become more widespread and more sophisticated. According to theorists such as Perrow and Beck (1992), however, such complex globally interconnected systems may actually be more vulnerable to small disruptions at key points, because of their large knock-on effects, than would be the case in a world with more localised self-sufficiency.

Table 6.2 provides some basic data to allow a comparison between London and the other cities (Wright, 2002).

Table 6.2 Summer and winter extreme temperatures for London and 'competitor' cities

Station	Latitude	Longitude	Elevation (metres)	Annual max Temp. (°C)	Annual min Temp. (°C)
London (Heathrow Airport)	51.48N	0.45W	24	30.5	-6.3
Toronto	43.67	79.63W	173	33.1	-24.0
Paris (Orly Airport)	48.73N	2.40E	96	33.4	-8.2
Berlin	52.47N	13.40E	49	33.8	-12.2
Rome	41.80N	12.23E	3	34.4	-3.2
Tokyo	35.55N	139.78E	8	34.4	-2.6
New York (JFK Airport)*	40.65N	73.78W	7	35.3	-14.7
Madrid	40.45N	3.55W	582	38.9	-6.8

* John F Kennedy Airport is within the urban area, but adjacent to the sea so likely to be cooler than central New York.

Most of the competitor cities to London have a higher temperature baseline than London, and are likely to remain hotter than London in the future due to climate change, though not necessarily by the same difference as currently. As shown in Table 6.2, London has the coolest summers of all the cities. Its winters are colder than Rome and Tokyo, though not as cold as Madrid despite London's much more northerly location. Toronto is the closest to London in summer extremes, both cities being slightly cooler than Paris. Toronto has much more extreme winters than London, however, whilst Paris is only marginally colder than London.

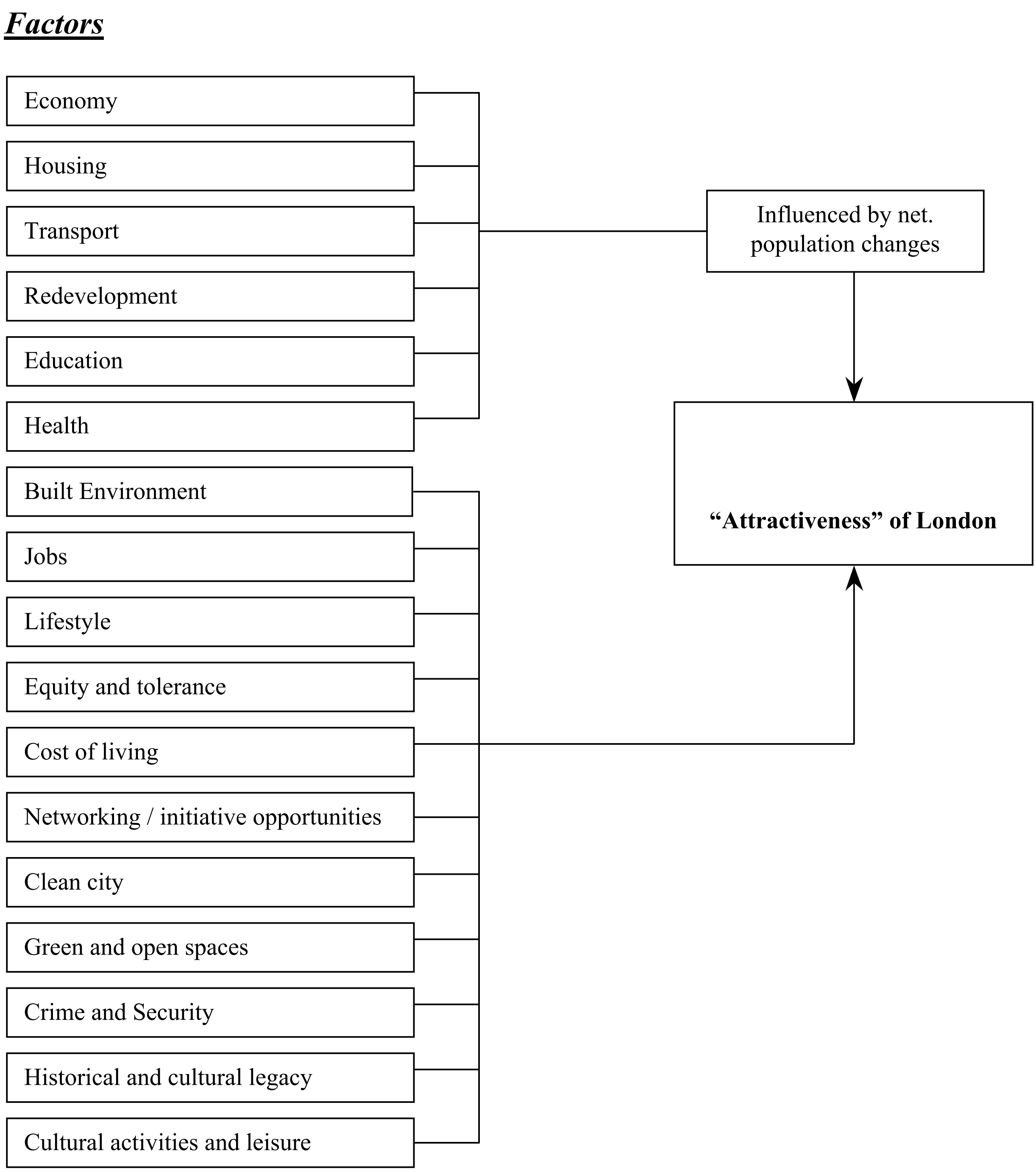
Tokyo and New York are noticeably hotter and more humid than London already. Both cities are coastally-located and therefore vulnerable to sea-level rise. As the Metro East study covering New York City expresses it: "*Many of the region's most significant infrastructural facilities will be at increased risk to damage resulting from augmented storm surges*" (Rosenzweig & Solecki 2001a:7). It is difficult to compare the UKCIP02 scenarios with existing studies of climate change in New York and Japan because different climate models and specifications have been employed. Nevertheless, the range of temperature changes for Japan (0.7 to 3°C for a doubling of pre-industrial CO_2 concentration which will occur before 2050, Nishioka & Harasawa 1998) and for New York (1.4 to 3.6°C by the 2050s and 2.4 to 5.7°C by the 2080s) (Rosenzweig & Solecki 2001), are reasonably similar to those suggested for London. Rainfall changes are more difficult to compare, and for New York at least, they vary significantly with respect to the different climate models used. As for extreme events, New York experienced major heat waves in the summer of 1999 and in September 1999, Tropical Storm Floyd brought large-scale flooding in northern New Jersey and southern New York State (Rosenzweig & Solecki 2001).

6.5 Attractiveness

We propose here to analyse the potential social impacts of climate change upon London by employing the notion of *'attractiveness'*. Attractiveness is made up of a combination of factors: economic, lifestyle, socio-cultural, opportunities, cost of living, land availability, and so on.

Figure 6.2 aims to illustrate this idea. ‘Attractiveness’ is an inherently subjective concept: whilst some people love heat waves, others find them oppressive; whilst some would welcome a more outdoors lifestyle, there are others who regard the associated noise and visibility of others to be intrusive. There are, however, some changes whose effects upon attractiveness we can be a bit clearer about: few if any would welcome a hotter journey on the tube, or parched, dusty parks and gardens, or hosepipe bans, for example. In the following we have provided judgements on attractiveness which are based upon expert and stakeholder discussions, infused with our own judgements based on past work on regional climate change impacts and a review of the literature. (Note that some dimensions of attractiveness are discussed more completely in Section 7, e.g. transport and tourism). A summary diagram of the changes in attractiveness due to climate change is given in the Summary and Conclusion to this section.

Figure 6.2 Factors Contributing towards the 'Attractiveness' of London as a city



London's attractiveness emerges from its role within the UK as centre of government, commerce, finance, other business services, the media, creative arts, etc. The sheer concentration of these activities and associated resources generates its own momentum and accelerates further concentration. London becomes a 'magnet' for many seeking their professional development, family and friends, likeminded people, involvement in national-scale organisations, networks, events and activities and so on. The 'pull' of London is therefore an upward spiral – the more people are attracted because of these reasons, the more reasons there are to attract others. The risk is that some set of circumstances might trigger a reversal of this process, resulting in a negative spiral (as witnessed in the past several decades in many towns and cities in the north of England). House prices, pollution, poor infrastructure, lack of health care, crime and so on, could all contribute to such a reversal, though the underlying economic conditions are likely to be the most important factors.

MORI's survey work for the GLA over the past two years provides evidence of the attractiveness of London. More people agreed that London had a positive rather than a negative record for culture and leisure, tolerance, parks and open spaces, easy accessibility, good relations between sections of the community, less discrimination than in the past, good schools and accessibility for people with disabilities (GLA 2002). Only on three issues did London score a more negative than positive record: availability of good quality health services, being a 'green city' and 'clean' city. The fact that 75% of respondents thought that London is *not* a clean city is highly significant to this study.

About a quarter of MORI's respondents were 'very satisfied' with London as a place to live and another half were 'satisfied', only one in ten said they were dissatisfied. It is interesting to note that a larger number of people are 'very satisfied' (about a 1/3rd of respondents) with their neighbourhood rather than with London as a whole. That could indicate the negative aspects of being part of Greater London which are not necessarily so evident locally, or which are more readily adapted to locally through familiarity and experience. On the negative side, when asked whether their neighbourhood is getting better or worse, 38% of people said it was getting worse, compared to 24% who thought it was improving (GLA 2001). The corresponding figures for London as a whole were 47 and 19% respectively.

The perception of negative costs associated with living in Greater London (as opposed to the respondents' own neighbourhood) appears to be becoming more pronounced. Judging by the responses elsewhere in the MORI survey, these negative costs appear to be crime and security, cost of living, traffic congestion, lack of public transport and problems with public services (health and education). Slightly more than 1/3rd of respondents said that they would tend to agree or strongly agreed that they would move out of London 'if they could'. This is higher than the 20% of respondents who, in a separately posed question, thought that they were certain, very likely or fairly likely to move out of London. One interpretation of this is that 10% or so of the respondents do not feel able to move but would quite like to if they could.

We should note that a major limitation of the use of MORI data here is that we do not have a comparator data-set for other cities in the UK, EU and further afield. If we had had such data, we would have been able to get a much better understanding of the relative attractiveness of different cities, against which the impacts of climate change could have been evaluated. Unfortunately, such detailed survey data is only available for London as far as we have been able to ascertain. There are perhaps fewer incentives for those in London to leave the city than residents of other parts of the UK because opportunities are generally higher in the capital than elsewhere. By contrast, there is a shift of population from the north to the south east of England because of declining opportunities in the north.

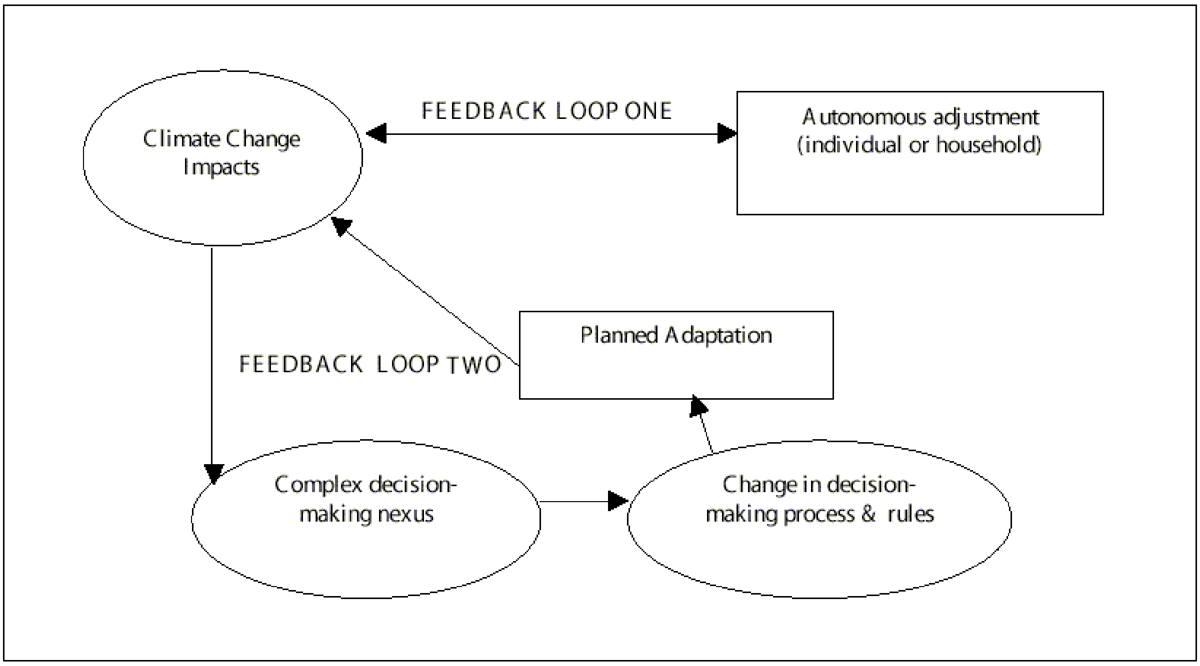
Social mobility is less pronounced in less affluent parts of society and many people stay in one place for social, family and cultural reasons. This creates a certain 'inertia' in demographic trends and patterns, which means that only a proportion of the population will respond to perceived changes in 'attractiveness', at least in the short-term. Evidence for such inertia can be found in the response of populations in the north of England to sustained economic decline in the past 30 years. Whilst there has been some net outward migration, it has not been anywhere near the level that would be implied by the relative difference in fortunes between South East and London and the north in terms of economic growth and job opportunities. (Part of London's workforce would, however, be likely to have more transferable and desirable skills than those in what was a largely manufacturing-based economy). The cultural, family and 'familiarity' ties which keep people in the area they grew-up in or have lived in for a considerable time, are strong and enduring. This does not detract from the value of the concept of 'attractiveness' since a less mobile individual, household or organisation may still wish to know what, on balance, the impacts of climate change might be (hence how to respond, if at all).

How, then, might climate change affect London's attractiveness - the strength of the magnet which is the capital? And what are the potential consequences of such change?

6.6 Autonomous Adjustment and Planned Adaptation

We now present the potential direct and indirect impacts of climate change upon the factors which contribute to, or detract from, the attractiveness of London, as identified in Figure 6.2 above. As pointed out in one of the workshops, human systems are inherently adaptive and responsive to change in conditions. A useful distinction suggested in the workshop and in the literature is that between what has been termed '**autonomous adjustment**' and '**planned adaptation**'. Autonomous adjustment whereby individuals respond to change through minor adjustments in their lifestyle, practices and behaviours. If hotter drier summers occur, then it is likely that lifestyle changes would follow on the part of millions of Londoners. Many people would probably spend more time outdoors, dress differently, eat different foods, spend their leisure time differently, grow different plants in the garden, and so on. Such changes are not 'planned-for' as such by organisations: usually they are decisions taken at the individual or household scale. (Though planning might encourage and facilitate change to occur in one direction rather than another: your local garden centre might not stock 'drought resistant' plants for example). It is assumed that the relevant actors would have access to resources to enable autonomous adjustment to take place. On the other hand, **'planned adaptation**' involves multiple-actors, change in organisations and policy making and decision-making rules and processes. Protecting development from the consequences of flooding is a good example here; once a particular development has been designed and constructed in a specific location, there are built-in vulnerabilities, which are to some extent irrespective of how individuals might respond to a flood event.

Figure 6.3 Autonomous Adjustment and Planned Adaptation [*source: Simon Shackley*]



It is not really possible (or sensible) to separate autonomous adjustments from the impacts of climate change, because it is a closely coupled system (Feedback Loop One in Figure 6.3). On the other hand, planned adaptation requires significant choices to be made in how the potential or perceived impacts of climate change are in reality responded to. Hence, for these types of issues, it makes sense to distinguish more clearly between impacts and responses.

Inevitably, in a report of this nature, there are some overlaps with the economic impacts section, and therefore, to avoid repetition, where appropriate certain social impacts have been combined with the economic impacts section. The opposite has also been applied with the economic impacts section.

For consistency, each section of the social and economic impact section is subdivided up according to the impacts of different climatic variables. Relevant discussion and case studies are included in each section as appropriate.

6.7 Built Environment

6.7.1 Context

There are currently 26.7 million square meters of office space in London. About three-quarters of this is in the central sub-region or in the eastern sub-region close to the centre. The amount of new office space required in the next 15 years is set out in the draft London Plan (GLA 2002a). This shows the need for significant new capacity (0.5 to 0.7 million square meters per year over the plan period, significantly more than was being added in the 1990s) (ibid.). Most (80%) of this new office space will be required in the central and eastern sub-regions.

In this section we consider the implications of a changed climate upon the built environment. We start by summarising the change in the urban winter and summer air temperatures arising from changes in greenhouse gas emissions and the urban heat island effect. The bulk of the section assesses the effects of these changes upon the heating and cooling requirements of commercial buildings (the domestic building stock being dealt with in the next section). Much of the analysis was done specifically for this project, and more details can be found in Wright (2002). We also cover the potential impacts of a change in rainfall patterns.

The Changing Climate

In the future (Wright, 2002; Wilby [This document, Section 5]):

- *Warmer winters are expected in London*, which will reduce heating requirements. The number of heating degree days (roughly proportional to the space-heating requirements in a well-heated building) will fall by between about 20 and 40% depending on emissions scenario, by the 2080s.
- *Trend in the magnitude of the central London heat island:* All seasons *except winter* show the difference between rural and urban temperatures increases over the 21st century. Over the heating season (October – April) it remains approximately constant. This means that the *difference* between heating requirements around the centre of London, and the suburbs, will not change.
- *Summers in London are expected to become warmer and drier*. The heat island effect also increases in summer. However, the regional rise in temperature is much more important (of the order of 1 to 3°C) than the *increase* in heat island effect (of the order of 0 to 0.5°C).
- *Summer evenings will be warmer*. Each 1°C warming on summer nights equates on average to more than an hour shift in the diurnal cycle; temperatures currently experienced at 7pm would be experienced well after 8pm.
- *The frequency and intensity of summer hot spells will increase.* The temperature exceeded on average on one in 10 summer days will increase by between 4 and 7°C under climate change, depending on emissions scenario. This is approximately double the increase in seasonal mean temperatures. Assuming the annual extreme maximum temperature changes by a similar amount, from Table 6.2, London's summer extreme would be about 33.5ºC by the 2050s in the two Medium Emissions scenarios, comparable with present-day Paris or Berlin. In the 2080s this rises to 35ºC under the Medium-Low Emissions scenario, similar to present-day Tokyo and New York. Note this is also hotter than all the present-day European cities at a similar latitude.
- However, since New York is about 11º latitude further south than London, it experiences much stronger sunshine – sun strength on clear days is largely determined by solar geometry and hence unaffected by climate change. Therefore, although temperatures may be similar, the weather would never feel quite like present-day New York. Cloud cover does decrease however in summer, by between 8 and 17%, depending on scenario, by the 2080s so there will be more sunshine on average. Note, however, that the level of confidence on changes in cloudiness is given as 'low' in the UKCIP02 scenarios. This compares with high

levels of confidence for general temperature increase. [See UKCIP (2002) for details of confidence levels].

- *London will not often suffer the very high humidity and high temperatures typical of cities like Toronto and New York.* By the 2080s the reduction in relative humidity ranges from about -7% under the Low Emissions scenario to about –14% for the High Emissions, compared to typical summer values around 60-70%. Therefore higher temperatures will to some extent be counteracted by reduced humidity.

So, under the two Medium emissions scenarios, around the second half of the century:

- Average summer temperatures outside London would be similar to those in the present-day city centre, though with a different diurnal pattern;

- If the urban heat island effect could be eliminated through dramatic changes to the cityscape, city centre temperatures would be similar to now, though again with a different diurnal pattern.

Climate change and the urban heat island already occurs in competitor cities of course. Comparison of the temperatures in Tokyo now and in the 1830s shows that they are on average about 4°C higher today (Tanaka, pers.com.) and 2.9°C higher over the past century (Reuters 2002). The number of nights during which temperatures stay above 25°C has doubled over the past 30 years (Reuters 2002). On one hot day in July 1995, there was a 7°C difference between the outskirts and centre of Tokyo (which nearly reached 39°C). The urban heat island intensity in Tokyo has been increasing in a linear fashion through out the 1990s, probably due to increased demand for summer cooling, higher traffic levels and greater use of computers (Tanaka, pers.com.).

6.7.2 Flooding and Rainfall Intensity Impacts

The building industry will benefit from an increased number of available construction days; in summer due to fewer rain days and in winter due to fewer frosts (although possible risk of increased waterlogging). If higher winds were to occur, there would be implications for the safe use of construction equipment, such as cranes and scaffolding.

The rise in groundwater levels in London due to changes in abstraction could be accelerated by increased winter rainfall although this is uncertain. One of the concerns of this is that the rising groundwater may build-up pressure beneath the clay layer which sits above the water containing chalk (the aquifer), thereby slowly increasing the saturation of the clay. This could affect the stability of certain foundations, in particular of tall buildings, and also of tunnels, which are drilled through the clay, resulting in subsidence and heave problems (ABI 2002). Plans to use some of this groundwater to alleviate the emerging supply-demand imbalance would clearly limit the problem (indeed, this issue is being addressed by The General Aquifer Research Development and Investigation Team or GARDIT, an informal group of interested parties derived from its three original members, Thames Water, London Underground Ltd and the Environment Agency set up to address the rising groundwater problem). On the other hand increased summer dry periods could lead to building subsidence due to drying out of clay soils, which is the dominant soil type in London.

Building design also needs to take full account of future potential water constraints, through use of ‘grey water’ recycling and other water conservation practices. Could new buildings in

London benefit from the rising ground water levels by using such water for flushing toilets, etc.? Could such ground water use also assist in the cooling of buildings in the summer, given that it will be significantly cooler than the air temperature?

6.7.3 Temperature Change Impacts

Effects on Heating

Non-domestic buildings and dwellings of those not in fuel poverty, are generally well heated, i.e. to a constant temperature during occupied hours. For these, the future reduction in heating degree days should be reflected approximately *pro rata*. Many non-domestic buildings such as offices and shops have high internal heat gains and therefore require cooling in all except cold winter weather. Increases in winter temperatures, and even larger increases in spring and autumn temperatures, will significantly increase the cooling loads in such buildings and bring more buildings into this type of regime.

Impacts on Air Conditioned Commercial Buildings

Analysis has been carried out on the effects of the urban heat island on cooling for a typical air conditioned office building in London, with no particular efforts made to reduce cooling demand such as solar shading. Using a derived relationship between cooling energy and average summer temperature, the percentage change in cooling energy was estimated (See Table 6.3). Increases are over 10% by the 2050s and around 20% in the 2080s. Cooling loads in many buildings increase greatly in sunshine where shading is poor; since cloud cover will reduce in future decades, this is likely to increase loads above those given. These increases are likely to be compounded further by a large increase in the number of buildings with cooling, in the absence of restraining factors.

Table 6.3 Increase in cooling energy compared to 1961-2000 for standard air conditioned building, by simulation

Emissions Scenario	Increase in cooling demand (%)		
	2020s	2050s	2080s
Medium-Low	7	12	18
Medium-High	7	15	26

Impacts on Non Air Conditioned Commercial Buildings

Building simulations for the 2050s conducted by the Tyndall Centre under a Medium-high UKCIP98 climate scenario, have explored the impact of future temperatures upon a smallish commercial property in London (Connor, 2002). Working conditions would be outside established 'comfort levels' for 451 hours or 23% of working hours. The use of best-practice natural ventilation and green design could reduce this to 169 hours or 8% of working hours, still a significant amount of time and outside the annual 'comfort' criterion. It is worth noting that the 'established comfort level' remains controversial and certainly not a mandatory standard, with some arguing that it should be relaxed or scrapped in favour of individual client/designer arrangements.

These results are in line with other work which has shown that in order to meet the comfort criterion even outside the centre of London for a present-day 'hot' summer, several features have to be included in the building design to lower indoor temperatures. Examples are high thermal mass, solar shading and natural (windows open) or mechanical (fans) night-time ventilation. Most of these features are lacking in existing buildings, and are expensive, difficult or impossible to retrofit. Night ventilation is one measure which is very effective outside London and often feasible to retrofit (though window opening must be designed to avoid a security risk). But since the urban heat island effect is at its greatest at night in summer, already raising the city temperature by about 3°C overnight and slightly more in the future, the effectiveness of night ventilation will be considerably reduced compared to non-urban areas. Also, summer cooling relies on high ventilation rates largely or totally provided by open windows. With high noise levels from traffic and pedestrians in much of London, this may not be a practical option.

The inevitable conclusion is that much of the existing commercial building stock is likely to be often uncomfortably warm later this century. This includes many existing buildings currently without air conditioning, and new buildings which have not been designed for summer conditions. Many clients and designers are therefore likely to go down the higher energy air conditioning route with more predictable internal conditions. One compromise approach which can result in a low-energy but comfortable building is the use of 'mixed-mode' operation. Here, the building is designed to be cool in summer with natural ventilation most of the time, but a limited amount of cooling is provided during the hottest periods to limit internal temperatures to (say) 25ºC, thus automatically satisfying the comfort criterion. The mixed-mode approach has been used successfully in many recent buildings, but is not standard practice. Buildings could be designed to minimise internal gains and take full advantage of natural ventilation, whilst leaving open the possibility of incorporating AC at a later stage should this prove to be necessary. One could, for example, put in high ceilings to leave space for chilled beams or ductwork, though there would be a higher initial construction cost. Such inherently flexible approaches could be a useful response to the uncertainty inherent in climate change because under a low climate change scenario, natural ventilation may be sufficient. Use of natural ventilation wherever possible within a mixed-mode operation reduces the AC load, thereby limiting the energy use and running costs.

There is also the possibility for significant innovation into more sustainable forms of cooling buildings. For example, chilled water could be provided by district Combined Heat and Power, perhaps powered with fuel cells (as adopted by Woking Borough Council). Borehole water could be utilised for cooling, with fuel-cell driven pumps, where it can be abstracted sustainably. Photovoltaics could be used in place of expensive cladding on prestigious buildings to provide electricity for air conditioning: the supply of PV electricity coinciding with high cooling demand.

Building specifications in the commercial sector in the UK, and London in particular, have frequently been driven by the perceived need on the part of property developers to provide a high quality development, thereby increasing the range of potential occupants, but not really taking full account of the client's energy costs (Guy & Shove 2000). Changing current practices, such that a sustainable response to climate change is feasible, may therefore involve a different approach to how building specifications are made.

Even if a building is air conditioned, such cooling is usually set to go on and off during conventional office hours. Hence, those who wish to stay late or start early might find that they are having to put up with higher than desirable or acceptable office temperatures, with knock-on effects for health and productivity. So, climate change could indirectly limit flexible working patterns, even though the latter have some advantages in reducing traffic congestion, since they spread the traffic load through out a wider range of hours than just the rush-hours.

6.7.4 Socio-Economic Scenario Differences

Under GM there would be continued pressure to install AC in all new buildings, whilst under RS there would be strong pressure (possibly through the planning system) for architects and developers to use natural ventilation or at least mixed mode. The use of buildings would also vary significantly between these different scenarios. In GM, there would be stronger demand for, and a faster turn-around in, commercial and domestic rentals. This would put the developers in a stronger position vis-à-vis building users, and might increase the pressure for the routine installation of AC (because developers wish to extract greater rents and maximise attractiveness of their buildings to a potential range of occupants, both of which tend to enhance building specifications (Guy & Shove 2000)). In RS, we might well see longer-term use of domestic and commercial buildings, with greater user involvement in design and specification accompanying the longer tenancy agreements. This would put more emphasis upon running costs and hence encourage the uptake of more energy efficient features in buildings.

Under GM, we can envisage new ‘landmark’ buildings, e.g. tall and striking office blocks, grand development of apartment blocks or retail centres, large bridges, and visitor attractions (e.g. emulating the success of the London Eye). Under the lower economic growth rates in the RS scenario, it is unlikely that there would be sufficient resources to support such grand developments, and there would probably be less demand for such buildings. Lower buildings would be preferred, but there would be some different forms of architectural innovation, e.g. for more sustainable designs.

Demand for green spaces would have to compete with demand for land to build upon in the GM scenario. This would tend to restrict extensive outdoor areas and gardens attached to new buildings to the higher end of the market. Under RS, planning would be used to achieve much higher levels of green space development in the urban context. Parks, gardens, open areas, street trees, and so forth, would become a standard element of new development and redevelopment.

6.7.5 Adaptation and Mitigation

Adaptation and mitigation are closely related for the urban environment; many single measures will have effects on both. For example planting trees reduces summer temperatures (adaptation) and cooling loads (mitigation), while installing cooling limits internal temperatures (adaptation) but increases emissions of greenhouse gases (negative impact on mitigation). Climate change should cause few problems in winter vis-à-vis temperature change and heating, hence energy consumption, is reduced. The main problems occur in summer, with higher temperatures and solar gain. Many of the measures to reduce the effects of the urban heat island, as described in Graves et al., 2001 will also have positive mitigation and adaptation climate change effects. In summary (Wright, 2002) these include:

- reducing the H/W ratio, where H is building height and W is spacing (width) between buildings;
- reducing anthropogenic gains, by having low energy buildings and less traffic;
- increasing vegetation and tree planting (several positive effects, and weak negative effects);
- fountains and open water;
- increased albedo – overall reflectiveness – with light-coloured building and street surfaces;
- solar shading on buildings;
- natural ventilation, mixed-mode operation and low energy air conditioning (in order of preference).

Much can be learnt from traditional approaches in hotter cities with high solar gain. In these, light coloured, heavy buildings, careful natural ventilation design, small shaded windows, garden courtyards with fountains, tree-lined avenues, etc., have over many centuries provided pleasant environments without any mechanical cooling systems. One could envisage future planning requirements for tree planting, or minimum reflectivities for building and street surfaces.

6.8 The Domestic Sector

6.8.1 Context

There are 3.1 million dwellings in London. 60% of these are owner-occupied and nearly a half are flats, a much higher proportion than for the UK as a whole (where flats comprise 20% of dwellings). In inner London, about three quarters of dwellings are flats. The latest housing survey showed that 7.7% of London's housing (237,000 properties) is classified as 'unfit' a slight drop from the previous survey (LHC 2002). The proportion is higher (13.2%) in the 'older' London Boroughs, with the greatest difference between Haringey and Sutton (an eight-fold difference) (LHC 2002).

The average London property now costs £205,850, the price having risen by 115% since 1995 (GLA 2002a). To purchase such a property would require a wage of at least £55,000. The average London wage is £34,777, however (GLA 2002a). Given such high house prices and high levels of poverty in sections of the community, it is not surprising that there are 52,000 households in temporary accommodation in London, 8000 of which are in Bed and Breakfast accommodation. Over-crowding is also common, and six times the UK average. The over-crowding problem is especially apparent in the Bangladeshi community (LHC 2002). Much has been written about the number of new dwellings required in London, discussed and reviewed in the draft London Plan, which concludes that there is a need for 31,900 new dwellings each year for the next 15 years (including rehousing requirements).

Four out of five respondents (77%) in the 2001 MORI survey (commissioned by the GLA) on living in London mentioned affordable housing as a problem and half of the respondents thought that making housing affordable is a top priority to improve living in the city. London is set to build nearly 500,000 new houses over the next fifteen years. The draft London Plan has proposed that a half of these should be ‘affordable’ housing. These houses will have to be designed and constructed with climate change in mind; existing housing stock may also have to be adapted to cope with increased summer temperatures, more winter rainfall and, arguably, more extreme weather events. Already we are seeing air conditioning being used in the domestic sector, and this trend is likely to continue given projections of climate change.

6.8.2 Changes in rainfall and water resources

Water shortages in the summer could result in more frequent non-essential use water restrictions which would affect households which have got used to abundant water supplies. It might be supposed that London would have a lower per capita water consumption than the UK average, because gardens in London are probably smaller. Somewhat surprisingly, however, the per capita consumption of water in London is actually higher than the UK average (155 litres per head per day compared to the national average of 146 litres per day). The reasons for this appear to be two-fold:

- Greater affluence in London leads to higher levels of ownership of water consuming devices (washing machines, dishwashers, power showers, etc.)
- The lower household size in London relative to the UK as a whole (as occupancy levels decrease, per capita water consumption increases). (Tattersall, Thames Water, pers.com.).

Without behavioural change, household demand for water in a hotter climate would increase due to more clothes washing, more showers, more water for gardens and so on. Lack of water for irrigation of parks and gardens, and for street cleaning would have an adverse effect upon the image of London, especially for visitors. It is likely that that non essential use restrictions would be imposed to manage a drought situation, with the introduction of rota cuts and standpipes being a last resort measure with a range of demand management measures being introduced between these two extremes.

The five Water Companies that supply London are Thames Water, Three Valleys, North Surrey, Essex and Suffolk and Sutton and East Surrey Water. Thames Water is the largest supplier of water and has a well distributed groundwater resources and the major surface water resources, all of which is managed as an integrated system (ibid.). Groundwater storage is used to compensate in part for the lack of rainfall over a number of seasons. Thames Water also has the advantage that it is abstracting water for London close to the tidal interface, which means that it can extract more water for public supplies (DeGaris, pers.com.). However the utilisation of this source has a number of issues including navigation, tideway water quality and ecology. Three Valleys relies largely on groundwater sources though does have surface water source from the Thames near Iver. They also import water from Grafham reservoir in Anglian Region. Thames Water is the only water supplier with large reservoir storage facilities within Thames Valley basin. These reservoirs allow greater resilience and there were no drought orders in the Thames Region in 1995. Reservoir storage was, however, falling at 1% per day in the 1995 drought, so it cannot be claimed that London’s water supply system is 100% robust in a single year drought event (ibid.). Resource stress would, therefore, only be apparent over a longer period of low rainfall, e.g. extending over at least two winters (March, pers.com.). Water stress might also increase as a result of increasing demand for water from the environment. The benefits of groundwater storage could be reduced in this way, moving the system towards single year criticality (ibid.).

Adjusting to climate change requires a fully balanced and twin track strategy with actions to manage demand, reduce leakage and provide additional sustainable resources. Adjustments to water shortages at the household level might involve water conservation measures (such as installation of devices in toilet cisterns), use of water butts in garden, metering and tariff development, re-use (rainwater or grey water). In the commercial sector recycling of water in appropriately scaled commercial developments and pressure and flow management for taps in commercial premises. A more radical response could be the installation of water storage tanks in properties, though this would obviously carry with it high costs in terms of installation and redesign of properties which have been built without water tanks.

When considering flooding, the vulnerability of housing to floods is partly a function of its design and the materials used. Modern housing is more vulnerable to flood damage because of the greater use of chipboard floors, dry wall plasterboard, cavity insulation and so on, and design features such as lower thresholds to improve access (ABI 2002).

A pertinent question from the social impacts workshop for this study was just how many times households and individuals would need to be subjected to water shortages or to flood events before they would respond by, for example, installing water conservation measures, water tanks, or making the design of their homes more flood-proof. It was asked whether there is any empirical evidence of behavioural change at the household level in response to floods. We have not been able to find any empirical evidence on this question, though the Environment Agency is engaged in a research project on public perceptions of flooding and risk communication which may provide such information in due course.

Another interesting stakeholder point raised in the social impacts workshop was the provision of information on flood risk and subsidence risk to home owners and residents. It was pointed out some communities would be better at finding out information on flood risk than others. The agencies involved in house conveyancy would probably not bring issues such as flood risk to the attention of potential buyers, and hence some pro-active investigation and questioning by the buyer would be needed. Such a system suits the more affluent white-collar professionals than it does the socially excluded. Hence, the institutional mechanism for providing information can itself contribute to social inequity. A further twist here, however, is that those agencies who provide information on flood risk may find themselves liable to legal challenge on the basis that such uncertain information is affecting house prices.

6.8.3 Temperature Change Impacts

London contains a wider range of housing types than most UK cities, reflecting the greater disparity of incomes. While some live in fuel poverty (generally defined as spending more than 10% of income on fuel), for others fuel bills are of no consequence. Future changes in London's climate will affect different dwelling types in different ways, and have varying economic impacts on households. This section considers some of these impacts, firstly for heating which all homes need, and secondly for cooling which is at present used in only a small minority of homes.

For poorly heated buildings, including dwellings of those in fuel poverty, much of the reduction in heating demand will be taken in increased comfort; cold bedrooms will be less cold, living areas will be warmer. The heating season will also become shorter, with people turning heating on later in warmer autumns, and switching it off earlier in the spring. There will therefore be a very positive effect on winter comfort and heating costs.

Cooling in Domestic Buildings

Until a few years ago, air cooling was only found in a few luxury cars; now it is standard in many ordinary models. This is not the result of climate change, but an interaction between manufacturers and consumers generating a new market. Similarly, most large London hotels now have air conditioned rooms. At present, the UK space cooling market for housing is very small, but it is growing rapidly and concentrated in the south east and London where summers are hotter and wealth greater. Typical installations include luxury flats and housing, particularly in the London area. A recent example is the Kings Chelsea development, a conversion of a former nurses' home into 287 luxury apartments and 12 houses. All of these have electric heating and air conditioning, with prices starting at £350,000 (BSJ, April 2002).

A number of factors could create a rapid increase in domestic space cooling in London:

- Generally higher summer and autumn temperatures;
- More frequent very hot summers, triggering purchasing decisions;
- More cooling in cars and non-domestic buildings;
- More products (portable systems are already on sale in DIY stores);
- Strong marketing by house builders and manufacturers of cooling as 'added value';
- Encouragement by electricity suppliers to increase low summer demand.

Apart from small portable units, the most likely type of fixed system would use an air-cooled condenser on the outside of the building or fitted into a window, as already seen on smaller commercial buildings in London. These are cheap and simple to install, but relatively inefficient with high running costs, becoming less efficient at higher temperatures. They are also visually intrusive, and since they use fans can be noisy both on the inside and outside.

More insulation in older properties is a good adaptation response, since it not only keeps the heat out, but keeps the warmth in during winter. Alternatives such as ground-source or water-source cooling exist; the capital costs are higher but running costs lower due to greater efficiency, and with no equipment or noise outside the building. There are strong arguments against more domestic cooling:

- more electricity use and hence greenhouse gas emissions;
- higher energy costs for households;
- possible replacement of winter electricity peak with summer peak, straining networks;
- visual intrusion;
- noise pollution.

In Tokyo, only the poorer suburbs do not incorporate AC in domestic properties. There is encouragement of energy efficient appliances, computers, fridges, TVs, etc., in order to limit energy consumption, hence reduce waste heat production. Other innovative approaches being explored in Tokyo include 'green roofs', i.e. using vegetation grown on roof tops to limit heat gain and to increase heat loss by evapotranspiration from the roots of the trees and shrubs. Such green roofs do appear to have had some success in temperature moderation within buildings, but one downside is that they increase the humidity of the air in the immediate vicinity of the building. Chicago also has a programme of encouraging green roofs (www.cityofchicago.org/Environment/Airpollution). The Japanese Construction Ministry is also investigating constructing a large heat exchange system covering some 123 hectares in the centre of Tokyo, including the Marunouchi business district and Ginza shopping area (Reuters 2002). Water would be pumped in buried pipes and would collect waste heat from air conditioning systems before being sent to a heat exchange system on the Tokyo waterfront, where cooler sea water would be used to absorb the heat. The cooler water would then be pumped back to collect more waste heat from the city, cooling the local air temperature by between 0.4 and 2.5°C. The scheme is currently only an idea and would be expensive, costing about $350 million dollars (pay back time of 30 years due to lower air conditioning costs) (Reuters 2002).

Social Responses to Warmer Domestic Properties

A larger proportion of Londoners live in flats and apartments and in multiple occupancy dwellings than elsewhere in the UK. This limits the responses which can be undertaken to some extent, since you cannot simply 'go into the garden/backyard' to cool down. Very few of the flats being built in London have balconies, but this is a well established method for coping with high summer temperatures used in buildings on the continent. In the social impacts workshop conducted during this study, there was a joke about 'Affordable Balconies' for London, but more seriously it was proposed that building guidelines might explore whether outside space could be enhanced for all new domestic and commercial property.

Another obvious adjustment to hotter weather is to open windows and doors to let cooler air replace hotter inside air. This is not always feasible, however, due to the greater risk of crime arising from open doors and windows, as well as traffic noise and traffic-related pollution. One finding from the heat wave in Chicago in the mid-1990s was that poorer households felt less able to open doors and windows because they felt more vulnerable to crime (stakeholder input to workshop, May 2002). Given that security and crime consistently emerge as prime concerns of Londoners, and as the top priority for action to improve London as a place to live (MORI 2002), the reluctance to opening doors and windows could easily be as real a phenomenon in London as it is in cities such as Chicago. This would affect less affluent neighbourhoods disproportionately and hence increase social inequity.

A further adjustment to hotter weather is be outside more often. This would require dwellers of flats and apartments without balconies to utilise communal space, or public spaces such as parks and gardens, so increasing pressure upon these. Whether local parks would be sufficient to cope with a greater demand for more outdoor spaces is not known and depends upon behavioural change which is impossible to predict. There might well be 'improvisation' in such a situation, utilising street corners, areas outside shops, or outdoor facilities in pubs and cafes. Access to such areas would not be even, however, since they may not be designed to cope with those with disabilities for example. Also, such impromptu congregations are unlikely to be welcomed by all local residents, some of who would perhaps complain about noise and disruption, feel threatened, etc. An interesting question is whether newly-built housing today should incorporate design aspects that take account of the likely greater demand in future for more outdoors living. This might be at the individual dwelling level or communally, e.g. shared areas of barbecues, outdoor get togethers and entertaining, etc. In Australia, for instance, public

BBQs facilities are provided, at which individuals bring their own food to cook on payment of a small fee.

One indirect effect of more outdoors living could be greater noise pollution, exacerbated by open windows. This could result in disagreement and conflict between neighbours as an individual or household or community perceives itself to be adversely impacted by the noise of the other. It is not unreasonable to suppose that people would adjust to any adverse social repercussions of more outdoor lifestyles and find ways of coping; this does, after all, happen in many other countries in hotter climates (Spanish, Italian and French cities for example, though none are strictly comparable with London).

Benefits
Warmer winters should reduce winter fuel bills, which will save householders money. Warmer winters will also mean fewer cold-related deaths which, at the national scale, is a larger effect than increases in deaths from heat stress.

6.8.4 Socio-Economic Scenario Differences

Flood Risk and Water Resources
An important finding of research on the impacts of flooding is that much of the increased costs associated with flood events in the USA are accounted for by the increased exposure of households due to: a) development in floodplains and flood risk areas; b) greater affluence meaning greater damage costs (Pielke 1999, 2000). Put simply, the exposure risk is higher and people now own more possessions which are liable to be damaged when flooding happens. Hence, evidence of the increased costs of flood events over time cannot be used to argue that there has been an increase in serious flood events *per se*. A similar argument can be applied to the UK, where most households have accumulated more expensive electronic and electrical goods, furniture and furnishings, etc.

Under the GM scenario this trend towards more goods is likely to continue, whilst under RS it is more likely that there is a slow down in the accumulation of material goods, hence the costs of flooding would increase more slowly. Under GM, building in flood risk areas is perhaps more likely than under RS. High-quality development in GM would be likely to be associated with high levels of flood resistance and mitigation measures and associated reduced insurance premiums. For instance, private developers along the Thames would include suitable private flood risk measures (as occurs along stretches of the US coastline). Low-quality development, however, would presumably not be so well designed or protected through private-sector schemes, and hence it would suffer from insurance-led property blight if flooding were to occur.

As for water resources, under GM there would be a continued upward trend in the per capita water consumption arising from greater ownership of water using appliances and continued move towards single occupancy. Under RS, the per capita consumption would reduce due to a reversal in the trend towards lower household numbers and an emphasis on water use efficiency and conservation. Hence, pressures upon water supplies will be exacerbated under GM with high climate change, though the supply-demand balance would depend on what increases in water supply are planned-for.

Temperature Change
Under GM, we would envisage more individualistic lifestyles. More 'private' and individual solutions to hotter buildings would be sought. Hence, the richer households would simply install AC systems, and the waste heat from these would be distributed locally, increasing the problem of over heating for those (presumably less well off) without AC. Climate change would, therefore, indirectly increase inequality between the better- and worse-off. The high economic growth rate would ensure that AC is provided as standard in many new properties. It would also mean that AC could be retrofitted into much of the existing building stock. However, there would still be much cheaper property where AC is not installed for financial reasons, with potential increases in inequality.

More privately-owned open spaces would also be fenced-off and protected to prevent use by others. There would be an increasing tendency for private purchasing of parks and gardens in squares or other local areas, for example; these would then be closed-off to members of the public and only available to members with property rights or who are prepared to pay fees. Disputes over noise pollution might be heightened under GM and there would be more recourse to 'private' mechanisms for dealing with social conflict, e.g. use of the legal system for the wealthier members of society.

Under RS, by contrast, there would be a stronger tradition of communal living and a greater willingness to engage in outdoor social activities with neighbours. Also, the risks of crime would be reduced through neighbourhood watch schemes, etc. On the other hand, under RS there would be less resource available for the retrofit design of older properties, due to generally lower wealth and less disposable income in this scenario. There would be a preference for using natural ventilation for cooling of domestic and less prestigious commercial buildings, not only because it is deemed to be more sustainable, but also because of the extra costs imposed by AC, which are less readily absorbed in RS.

There is likely to be a greater demand for new housing under GM than RS, because of more single-occupancy (a consequence of the continued trend towards individualistic lifestyles) and more inward migration. Hence, the overall density of development would increase and potential problems of urban heat islands would become more severe. Under RS, however, more of the new build would probably be communal and there would be a preference for higher urban density in order to free-up more land for green spaces. The thermal mass of such development could, potentially, increase the heat discomfort experienced. Inclusion of natural ventilation in the design would assist the alleviation of high temperatures. It is not known (with out more detailed modelling) whether such approaches would work adequately with a lower level of climate change. Natural ventilation approaches would probably not be sufficient in an RS scenario for London with high climate change.

6.9 Education

6.9.1 Context

Educational performance varies considerably across London, with lowest performance in the inner city boroughs of Islington and Haringey, and the highest performance in the boroughs of Sutton, Kingston and Redbridge (LHC 2002).

6.9.2 Flooding and Rainfall Intensity Impacts

There is anecdotal evidence that flooding can be highly stressful to children, some of whom see any subsequent rainfall event as threatening (Shackley et al. 2001). Such behavioural and emotional impacts are likely to affect children's educational performance.

6.9.3 Other Climate Change Impacts

Higher temperatures may affect the ability of children in schools to concentrate. A change in the scheduling of the school day is one possible response, e.g. with an earlier start and earlier finish, as in French schools. This change could, however, have serious repercussions for the parent(s), as they might then not be able to collect children from schools, or be at home for them in the afternoons. A different type of response would be for the school day to change, e.g. with more time spent outdoors in the hottest parts of the day. The ability to change the school day in this way would, however, depend upon availability of outdoor areas, with appropriate shade. Redesign of school buildings and lay-out would be one planned adaptation to temperature change. Change in extreme weather could potentially have some unexpected impacts on children. Teachers have reported anecdotally that some children become more excitable and 'hyper-active' in periods of high winds. Direct behavioural impacts of extreme weather could contribute to enhanced feelings of vulnerability.

If climate change were to influence the demography of London, this would have a knock-on effect on the number of children requiring education. Impacts of climate change upon transport would effect the ability of children to get to and from school.

6.9.4 Socio-Economic Scenario Differences

Under Global Markets (GM), we would have more private-funding of education, and more parental choice of school and, possibly, more choice concerning the educational approach, learning style and assessment method. One could perhaps envisage more and earlier differentiation of pupils, based on evaluation of their particular and specific abilities. This could exacerbate differences between the 'haves' and the 'have nots'. Under GM there might also be more children in London needing to be educated (depending on the deficit in population replacement elsewhere in society). Hence, any impacts of climate change would be more keenly felt under GM than under RS. The response to higher temperatures in GM would be more air conditioning in wealthier schools, increasing energy bills.

6.10 Redevelopment and Movement of Population

6.10.1 Context

Large-scale development is planned to occur across Greater London. For the purposes of this study the most significant is the Thames Gateway, which is the largest regeneration project in the UK. Whilst we will focus upon the Thames Gateway in the following section, we should make it clear that similar issues will also apply to all new building which occurs in the flood plain, not just of the River Thames, but also of its tributaries. With the Channel Tunnel Rail Link (CTRL) now agreed, the regeneration is also of national and EU importance (TGLP, 2001). The overall aim is for the East of England and South East Economic Development Agencies (EEDA & SEEDA) to work alongside the Greater London Authority, the London Development Agency (LDA) and Transport for London (TfL) in focusing sustainable development on brownfield sites, in order to achieve wealth creation and social inclusion. The Mayor of London, Ken Livingstone, has articulated this vision as follows:

> *"All my life activity has been in the west. Now it is the turn of the East. Almost all the growth and economic dynamism has been in the sector to the west of London. East London has been neglected for so long but it will be a major engine for growth". (TGLP 2001:3).*

The London Development Agency has stated that:

> *"The Thames Gateway is one of the key locations best placed to deliver large scale sources of new employment to London's major concentrations of deprived communities in inner east London" (LDA, 2001).*

The draft London Plan (GLA 2002a) outlines the drivers which are likely to shift development from the west to the east, both north and south of the river. These include:

- The high cost of offices and housing in central, north and west London;
- The support by government for the Thames Gateway and the existence of well-established partnership mechanisms;
- The existence of 10 square kilometres of development land adjacent to the greatest concentrations of deprivation in London;
- Opportunities in adjacent North Kent and South Essex;
- Radically improved public transport networks, including phase 2 of the CTRL and new rail and river crossings.

The existence of good examples of success such as Canary Wharf, where investment and infrastructure (especially transport) has led to high quality business accommodation which supports, and builds upon, the success of the adjacent City.

The London boroughs of Lambeth, Southwark, Greenwich and Lewisham - all of which are adjacent to the River Thames - thus have a combined target of providing accommodation for approximately 93,000 households in the next 15 years. Similarly, the demand for office space in the East sub-region of Greater London is estimated to increase from 8.1 million square metres to 12 million square metres, accompanying a continuing shift away from manufacturing and towards service industries.

6.10.2 Flooding and Rainfall Intensity Impacts

The proposed Thames Gateway development occurs upstream (Canary Wharf, Isle of Dogs, Stratford, Leaside, Royals, Greenwich Peninsula, Lewisham, Deptford, Greenwich) and downstream (Barking, Havering Riverside, Woolwich, Belvedere and Erith) of the Thames Barrier (TGLP 2001, MCA 2001). The flood defences of the river downstream of the Thames Barrier include the Barking and Dartford Barriers, which operate at the mouth of tributaries into the Thames, privately operated smaller barriers, and refurbished sea walls and embankments. In the 1980s the sea walls along the Thames Estuary were rebuilt and the crest levels were raised by 2.5m. The Thames Barrier and the defences which are located downstream of the Barrier were designed to provide protection from flooding of a 0.1% risk in the year 2030.

As a consequence:

> *"the flood defence standard is about 1:2000 years or 0.05% risk of flooding. With sea level rise this will gradually decline, as planned, to a 1:1000 year or 0.1% risk of flooding by the year 2030. Thereafter, if improvements are not made the defence standard will continue to fall. Preliminary estimates of the cost of providing 0.1% standard to the year 2100 show that a major investment in the flood defences infrastructure of the order of £4bn may be required within the next 40 years" (Environment Agency 2002).*

The standard of flood protection of the Thames in London is high. Low-lying areas targeted by development plans for the Thames Gateway (Barking, Havering, Erith, etc.) are currently well-protected against the risk of flooding; nevertheless the risk does need to be recognised. Clearly, a 0.05% risk is relatively low and a higher standard of protection is applied to the Thames than that which is usually applied to riverine (1%) or estuarine & coastal (0.5%) flood protection in the UK. The residual risk of an extremely serious flood event overtopping or breaching the defences of course remains. Much of the development land in the Thames Gateway will consist of brownfield sites, and such land is frequently to be found in the flood plain. Many brownfield sites have been used for industrial purposes. The ABI notes that the vulnerability of housing and retail property to flood damage may be far greater than for many industrial uses because of the greater value of the assets exposed (ABI 2002).

It should be noted, nevertheless, that the economic and social costs of a 1 in 2000 year event (the level of protection which existing flood defences are currently estimated to provide) are likely to be highly significant for the local, national and international economies. The most significant of these costs are thought to be:

- Repair to private property – to be met by the household/business and/or insurance agents;
- Repair to public property – to be met by local and/or national taxpayer;
- Relocation costs of household, business and public administration;
- Preventative expenditures associated with building design that reduce flood risk further – to be met by developer/occupier (private property) or taxpayer (local authority-owned);
- Disruption to transport infrastructure and subsequent repairs.

There may also be an impact on the attractiveness of the London property market to overseas investors, and more generally, the attractiveness of the city as a place to conduct business of all sorts. These potential indirect effects have not been quantified but are clearly likely to be a major factor in the economic appraisal of future investments in flood prevention measures.

Related to this, a greater perceived flood risk along the Thames corridor may result in reluctance of businesses and households to live and work in at-risk areas. This type of economic blight may cause those who can afford to relocate to move to other areas of London or outside of London. These effects will cause land prices to rise in other parts of London and result in occupation of the blighted areas only by low-income groups.

A further important issue relating to the nature of economic development in London is the knock-on impacts of riverside development in East London in the next decade upon the requirement for future flood protection. Once major new infrastructure is constructed, then there is a large new asset base which needs to be protected and this in some senses limits (or renders less attractive) other options, such as using land for green areas which can serve a role in flood water storage. The issue is, in part, one of how long a time scale is adopted in analysing urban development and regeneration plans. If one were to adopt a timeframe of 15-20 years ahead (as used in traditional planning), then flood risk would probably not feature as an impediment to riverside development. Over a 50-100 year timeframe, the evaluation process would have to change because of the need to take account of the change in level of flood protection provided by the Thames tidal defences beyond 2030 (hence requiring use of a scenario planning approach).

An even longer timeframe, i.e. beyond 2100, would require yet another assessment, because of the accumulated effects of sea-level rise. Depending upon global greenhouse gas emissions and the uncertain response of the oceans and ice-caps, etc., sea-level rise over the next several hundred years could challenge the technical capacity to provide adequate levels of flood protection in parts of London. No thorough assessments of the risks of sea-level rise and extreme rainfall affecting the river level on these longer time-scales have yet been conducted.

Another issue for the Thames is the potential need to store large amounts of water up and down-stream of the Barrier depending on whether the issue is increased rainfall (up-stream) or higher sea-levels plus surge events (down-stream), or perhaps both. Re-channelling water out of the Thames upstream, and into other waterways is one option for coping with large amounts of accumulating river water. Down-stream water storage is required when the barrier is closed and this could, potentially, have an adverse impact upon fisheries and cockle beds, which are protected by EU legislation. Using the river and estuary for water storage purposes to avert flood risk could, therefore, collide with its natural ecosystem role and functions (Naylor, pers.com. 2002).

Several of the Strategic Zones of Change which have been identified within the Thames Gateway for London have included nature reserves, country parks and visitor centres, e.g. Havering Riverside and Rainham Marshes (a 1,400 ha reserve is proposed, with capacity for a quarter of a million visitors per year) (MCA 2001). There is clearly a good opportunity here for such set-aside land for biodiversity to double-up as land for flood water storage. The future of Rainham Marshes as London's biodiversity 'jewel in the crown', and one of the few remaining remnants of the marshes that once fringed the River Thames, now seems more certain, with the London Borough of Havering agreeing that the marshes should be protected (FoE 2002). In 1998, considerable concerns had been expressed when English Partnerships applied to Havering to build on 50 hectares of the area (FoE 1998). Interestingly, the lack of proper management of the site in the past had led the opinion to be expressed at that time that the Marshes were 'not worth protecting'.

The 142,000 new houses and 255,000 new jobs planned for the Thames Gateway (TGLP 2001) have huge knock-on implications for the provision of water resource and suitable sewerage treatment facilities, as identified by stakeholders in the course of the study. The design of the sewerage system clearly needs to avoid the prospect of overflow at times of high rainfall directly into the Thames. This high level of development also implies a quite massive urban development, which could increase water run-off. Potential solutions to this are greater use of sustainable drainage systems, permeable 'soakaways', and so on, though such methods are far from having been fully proven in a range of situations.

The Environment Agency (2002) and Thames Estuary Partnership are currently undertaking a comprehensive assessment of flood protection of the Thames Estuary, and it is proposed that this should extend its timeframe for assessment beyond 2100. The EA assessment will not be completed until at least 2006, however. Some of the development decisions in respect of Thames Gateway may be made in a shorter timeframe than that, e.g. purchase of land for redevelopment, provision of guidance, planning permissions, etc.

6.10.3 Temperature Change Impacts

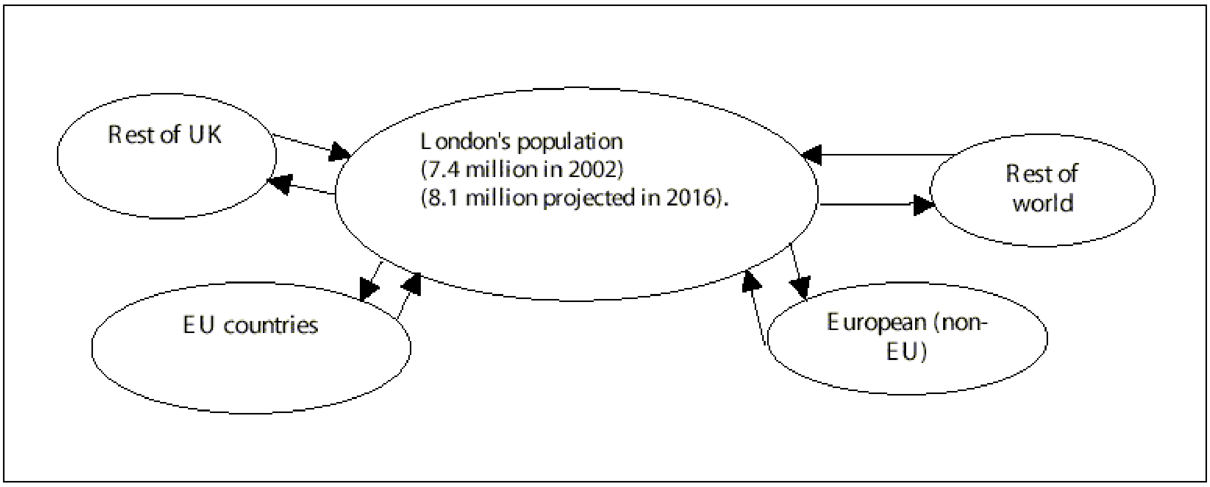
Major new development such as the Thames Gateway presents opportunities for innovative solutions to the problem of over-heating within domestic and commercial buildings. As well as natural ventilation and mixed-mode approaches, which can take advantage of the flow of cooler air up the river Thames, there is the potential to use heat exchanges with ground water and/or with the River Thames and its tributaries. Groundwater heat pumps could utilise the cooler underground waters for cooling of buildings, whilst heat exchangers extending into the river Thames would moderate temperatures in summer, also providing some warmth in the winter. The costs of such heat exchange systems are usually prohibitive, though in the case of a new development the costs would be relatively more contained. The new GLA City Hall building is showing a lead by having a borehole ground water cooling system.

6.10.4 Indirect Effects due to Demographic Changes

The demand for housing and associated infrastructure (work places, schools, hospitals, transport, etc.) depends on the net population in London, represented by Figure 6.4 below. The workshop discussed the possible impacts of climate change upon these population flows. It was thought that high climate change might increase the flow of people out of London, since these would mainly be retired and older people, who would be more attracted to a rural or suburban residence outside of London because of heat waves and heat discomfort. An additional outflow might be more seasonal, with wealthier inhabitants decamping in other cooler and cleaner locations in the UK or elsewhere.

There is currently a net outflow of UK citizens from London. In 1999, 163,000 people moved into London from elsewhere, whilst 197,000 moved out (ONS 2001). Birth rates per 1000 people in London is significantly higher (by 23%) than the UK average, reflecting the younger than average population of London compared to the UK average (ONS 2001). The flow of people into London from elsewhere in the UK would *not* be sensitive to climate change, it was felt, because the strong pull of the capital is for jobs and the other elements of attractiveness identified in Figure 6.2. Also, many of these inward UK migrants are younger and less likely to be put-off the city by the weather conditions. A proviso to this assessment, however, is if the ‘magnet effect’ of London is diminished by a reduction in its attractiveness (perhaps in a part because of climate change). In that case, more offices and HQs would be based outside of London, and the attractiveness of those other locations would increase relative to the capital. A further proviso is that if sea-level rise threatens coastal habitation in the south east and east of England (or indeed elsewhere in the UK) there could be an inward migration to London, either from abandonment of settlements or property blight due to cost or lack of availability of insurance protection.

Figure 6.4 Flows of People into and out of London



As for the flow of EU residents into London it was not felt that this would substantially change as a result of climate change. Other major European cities would be affected by climate change, but it is not obvious that there would a major exodus from these to London. If a 'critical threshold' were exceeded, e.g. for water supplies, then it is conceivable that some southern European cities would have to 'down-scale', though no evidence of such thresholds is presently available. Furthermore, the other major financial and business service centres (Paris, Berlin, Frankfurt, etc.) are located in northerly parts of Europe and inland, and much less likely to be subject to such critical climate-related thresholds (though there might be problems arising from summer temperature extremes). In the worst-case scenario, there would be very high climate changes and associated impacts in southern Europe, which would contribute towards a general northerly shift in the EU's population. The level of climate change and impacts would have to be rather extreme for this to happen, however. Many people in Europe appear to be more than content to live in their hotter southerly climates, however, and indeed they are joined by many thousands on holiday, or permanently to live, from the north of Europe. It appears that many citizens of the EU are not yet near the higher end of their 'preferred' temperature regime!

As for flows of *non*-EU residents into London, this might be more sensitive to the impacts of climate change in the areas where people are coming from. It was felt quite strongly, however, that by far the most powerful driver is the lack of economic opportunity in the host country. Climate change could reduce the economic fortunes of that country even more, though it could also have the converse effect, if there are agricultural benefits (relative to other countries). Hence, it was felt that too much importance should not be attached to climate change in understanding migration. The exception was where a major climate-related disaster or catastrophe struck (a drought, flood, storm, extended problems over water supply, etc.): in this case then there could be large-scale movements of people, 'environmental refugees' as they have been termed, though the UN does not currently recognise such refugees. Experts in refugee studies have stressed that environmental events by themselves rarely, if ever, produce 'refugees' (Barnett 2001). It is, instead, the accumulation of economic and social hardships, wars and (in some cases) environmental events, which produces refugees. This is not to say, however, that climate-related environmental threats might not become more of a problem in the future, as there is an acceleration of global environmental change. The political pressure generated by many more refugees would be significant.

To summarise, the workshop concluded that climate change would not substantially effect the net migration into and out of London. It could, however, accentuate the *existing* trends of outward migration and, to a lesser extent, inward migration, though to what extent is very difficult to assess, and possible effects are discussed in relation to the supply of labour for some industries, in the Economic Impacts section below. If climate change did influence the overall attractiveness of London as a global economic centre, then this could also influence net-migration.

6.10.5 Socio-Economic Scenario Differences

Under a GM world, the role of strategic planning and oversight of the development of land in east London would be fairly limited. It would be more or less the prerogative of private developers to decide on their own development strategies and priorities, within broadly construed, but not overly prescriptive, guidance. Under the RS scenario, planning would become much more important and there would be greater use of regulation and guidance, with an emphasis on 'appropriate development' given flood risk and urban redevelopment priorities. RS would favour 'green corridor' approaches (though in addition to, not at the expense of, green belt) with some managed retreat of the existing defences in selected locations.

6.10.6 Adaptation Options

There is some discussion within the Thames Gateway partners and London planning community of whether a green corridor alongside the south and north banks of the Thames could be included as an integral part of the Thames Gateway. This would, inevitably, limit the area of land available for redevelopment. Hence, there may be a need for more land to be made available elsewhere within the target development area. One idea that has been mooted, is to relax the Green Belt on the north easterly and easterly fringe of Greater London in certain locations, but then to compensate for the loss of green land by the creation of 'green corridors' that radiate from the outskirts into the inner city. Such green corridors would follow river valleys where possible (e.g. River Lee) and would have other social and environmental benefits (e.g. recreational and leisure use).

A more radical way to allow high levels of urban development in areas at risk from flooding might be to restrict the time span over which planning permission is granted. This would retain the flexibility over future policy options which is desired by the Environment Agency, whilst facilitating development which clearly has multiple economic and social benefits. Planning permission in a new development could be permitted, but only for, say, 50 years into the future. The construction and infrastructure would need to take full account of the limited time-span. In practice, however, it is very difficult to imagine whether the population of an area would ever accept the need to 'move on' and find somewhere else to live, especially since most of them would not be the same individuals who invested in the area originally. The financial prospects of investing in an area with a limited timespan is also doubtful, unless demand was extremely high and no other credible alternatives existed. Why, in the last analysis, would any one wish to buy or invest in a property in such an area, especially with elapse of time? Limiting the flood defence protection available to the area (to reduce the expectation that flood protection would be provided beyond the planning time horizon) would simply exacerbate the problem of 'property blight'.

6.11 Lifestyles and Consumption

6.11.1 Context

Lifestyles are highly diverse and changeable. Climate change could be significant in so much as it accentuates, facilitates or inhibits certain existing and on-going changes in lifestyle. The predominant drivers for lifestyle changes are, however, a complex mixture of social, cultural and economic factors and only tangentially related to environmental concerns for the majority of individuals and households. This might change in the future, of course, due to value-shifts (e.g. a shift to 'post-materialism'), or it might change because of adverse environmental impacts, such as droughts, heat-waves, floods, and so on.

6.11.2 Temperature Change Impacts

Climate change might accelerate a move towards more active, outdoor lifestyles and all-year around tourism. This trend is already in place, driven by greater affluence, earlier retirement, better health and a cultural shift away from the idea that older people cannot have an active lifestyle. Better weather can only accentuate the growing popularity of 'out of season' tourism, and would encourage more outdoors activities in general. Lifestyles become more outdoors oriented, increasing pressure upon open-spaces, and possibly increasing the demand to travel out of urban locations. Different populations have varying potential to adopt more outdoors lifestyles due to income, location of residence, dependants, and cultural issues. There are also implications for the design and styling of clothing, fashion, buildings, cars, and so on. This creates opportunities for designers who are looking to provide the market with – literally - 'cool' goods and brands. We have already seen the brewing industry using advertising that emphasises the cooling quality of their products, and even relating this to global warming. Such marketing (whether serious, ironic or playful) is likely to become more common in future.

6.11.3 Impacts due to Global Climate Change

There are also certain threats to the provision of taken-for-granted goods and services that might arise from disruption to production, manufacturing, distribution, storage and delivery caused by climate change (see also Section 7.7 on manufacturing). Yet, climate change might well increase the demand for fresh fruit and vegetables, cold water, ice creams, etc., including fresh foods and goods sourced from around the world. Given the highly international nature of food sourcing in UK supermarkets, what happens in Spain, France, Italy, Greece, Israel, North Africa, and so on, will influence availability and cost to UK retailers. Assessing the impacts of climate change upon food supplies in those countries is by no means straightforward, however. This is not only because of the scientific uncertainties but also because of the potential role of adaptation in moderating the impacts. It is also a consequence of the potential opportunities for new agricultural developments in other countries (e.g. in Eastern Europe), and in the UK itself, which could emerge through climate change plus socio-economic development.

6.11.4 Socio-Economic Scenario Differences

Under an optimistic GM scenario, new supplies of goods and services desired by consumers would be forthcoming. The assumption here is that climate change will bring opportunities for some producers, at the same time as others suffer. Entrepreneurial retailers will always be able to exploit these new opportunities. The GM scenario would also see greater affluence and greater longevity as health care improves for the well-off, who would therefore be even better predisposed to take advantage of new opportunities for tourism and leisure. The less well-off would, clearly, not share these opportunities to the same extent. Under the RS scenario, there would be a ratcheting-down of expectations concerning the availability of goods and services from around the world. There would be a greater focus on local production, and the low level of climate change could allow a wider range of food produce to be grown locally, with benefits for the local and UK economy.

High levels of climate change could, conceivably, accelerate the incidence of natural weather-related disasters. Accumulation of disasters and widespread social, economic and environmental impacts might encourage a shift in values, so moving away from the GM scenario. Under the RS scenario, a pattern of natural disasters would provide more evidence of the need for limiting the use of resources.

6.12 Health

6.12.1 Context

Health is regarded by most experts as being strongly related to socio-economic circumstances such as housing, employment, education and lifestyle (LHC 2002). The high levels of inequality in London mean that many of the additional impacts from climate change will be felt most acutely and with greatest consequence by the underprivileged. These would include those who are less well off, live in unfit and overcrowded housing, do not have fresh food readily available, suffer from higher unemployment, are less able to pay for suitable adjustment, and so on. One way to reduce the vulnerability of the population to climate change related health-impacts is therefore to reduce present-day inequalities.

6.12.2 Flooding and Rainfall Intensity Impacts

Flooding results in health impacts which have been investigated in several studies for the Environment Agency (e.g. by the Flood Hazard Research Centre, Middlesex University). Long-term effects upon stress and depression levels have also been studied (e.g. from the Northampton floods of 1998). It was pointed out by Sari Kovats of the London School of Hygiene and Tropical Medicine in one of the workshops, however, that there are significant methodological obstacles to measuring change in stress and depression levels following flooding. How does one know with any certainty what the baseline level of stress and depression was prior to the flood event?

6.12.3 Temperature Change Impacts

Warmer Winters

Of the roughly 70,000 deaths in London every year, about 6,000 more occur during the winter than would be expected from the rate during the rest of year. There is some evidence to link this to cold homes and age. Countries with much colder winter climates, but higher standards of heating and insulation (e.g. Sweden) have much lower excess winter death rates. While improved insulation and heating is far more important than changes in winter weather, a reduction in very cold spells is likely to reduce excess winter deaths over and above the effects of dwelling improvements. The Department of Health suggest that up to 20,000 fewer deaths might occur in the UK as a whole as a consequence of medium-high climate change by the

2050s (DoH 2002). Although winter precipitation is predicted to rise by around 10-20% in the London area, snowfall is expected to decrease by between 60% (Low Emissions scenario) and about 95% (High Emissions scenario) by the 2080s, indicative of far less frequent wintry spells.

Effects on humidity and related health effects are less certain. External relative humidity falls by 2-3% percent in winter under all scenarios and timescales, but absolute humidity rises since warmer air can hold more water. Since absolute humidity determines internal relative humidity in heated buildings, internal relative humidity could rise slightly. This, combined with higher internal temperatures, could increase asthma, since both tend to increase asthma rates. However, there will probably be less internal condensation and mould growth, because internal surfaces on external walls and windows will be less cold and this is likely to be a stronger effect than the slight rise in absolute humidity, with small beneficial effects on health. Predictions for wind remain very uncertain; wind speeds are expected to stay about the same, possibly increasingly slightly in winter, but the effects on infiltration rates and hence internal humidity are likely to be commensurately small.

Hotter Summers

Projected climate change will be accompanied by an increase in hot spells, often exacerbated by urban air pollution on still, hot days, which would cause an increase in heat related deaths and illness episodes (see Section 5.3). The evidence indicates that the impact would be greatest in urban populations, affecting particularly the elderly, sick and those without access to air conditioning. The Department of Health's recent review of the impacts of climate change suggests that approximately 2000 extra deaths might result from higher summer temperatures in the UK as a whole (DoH 2002).

Populations do, however, adapt to continued higher temperatures through behavioural change and through autonomous physiological change. For this reason, populations are most often vulnerable to unusually hot or cold weather, relative to what they are acclimatised to, rather than hot or cold *per se*. Studies have shown, for instance, that the people of Athens suffer more from a cold weather spell than people in Stockholm do to an equivalent cold spell. On the other hand, the residents of Stockholm are more affected by a heat wave than those in Athens (Martens 1996, Gawith et al. 1999). If climate change results in greater variability and more extreme events, then populations will, conceivably, become more vulnerable. Whether populations adjust to a more variable pattern of weather from month to month, or from year to year, is an interesting question. Adjustment to a certain level of variability is feasible, though thresholds may occur in the adaptive capacity. A further impact of hotter weather is the greater risk of skin cancer, especially for children who not only spend more time outside but are also the most vulnerable. The Department of Health (DoH) suggests that 30,000 additional cases of skin cancer could occur across the UK if ozone-depleting chemicals are emitted at current levels, though full implementation of the Copenhagen Amendment would reduce this number to 5000 (DoH 2002). The DoH review stresses that the additional number of cases of skin cancer depends greatly upon adjustments, such as use of sun creams, avoidance and wearing of wide-brimmed hats, and so on. An increase of up to 2000 more eye cataracts a year is also anticipated by the DoH review.

The outbreak of Legionnaire's disease in Barrow-in-Furness in August 2002 is widely expected to have been related to a faulty or poorly maintained air conditioning unit. As of early August, one man had died from the outbreak, whilst 117 people have been identified as having been infected. This highlights the potential risk that more widespread use of air conditioning could increase the incidence of Legionnaire's, if units are not correctly operated and maintained. In the light of the Barrow outbreak, more research is required on the risks arising from possible spread of infectious agents through use of air conditioning.

Other Health Impacts of Climate Change

Other effects on demand for health services arising from climate change include:

- An increase in instances of food poisoning (estimated at 10% increase, or 10,000 more cases, for the UK as a whole) as increased temperatures facilitate bacterial growth (DoH 2002), though again much depends on behavioural change.
- Those in over-crowded accommodation are more vulnerable to the spread of infectious diseases.
- The pattern of demand for health services might change, with somewhat less demand for treatment of cold-related illness in the winter as temperatures increase, though with the possibility of a slight increase in summer. Increases in severe weather events, particularly storms and flooding, will also intensify temporary demands on resources and require the development of improved emergency planning scenarios.
- Increased blooms of toxin-producing algae in summer bathing water. Such toxins can be very dangerous if ingested: children or pets are especially vulnerable whilst playing around affected water ways.
- Potential increase in exposure to infectious agents. The DoH review has concluded that by the 2050s under medium-high climate change, indigenous strains of malaria will re-establish themselves in the UK, but do not pose a health threat. There could be outbreaks of the more serious strain *Plasmodium vivax*, especially in low-lying salt marshes, and local inhabitants would be advised to avoid mosquito bites. This could, potentially, affect parts of the Thames Estuary. The more serious strain *Plasmodium falciparum* would not become established in the UK, but tourists abroad could be vulnerable. Other countries are more vulnerable to climate-change induced changes in mosquito distribution, including parts of southern Europe and the southern USA.
- The risks of tick-borne diseases (Lyme Disease and encephalitis) are unlikely to increase according to the DoH review (DoH 2002).
- The risks of water-borne diseases such as cholera and typhoid are very unlikely to increase due to stringent levels of water quality treatment and control (DoH 2002).
- Less conducive working conditions due to hot weather and lack of air conditioning (e.g. in factories, in offices where AC cannot be afforded, etc.) can contribute to poor health. Even in those buildings with AC, the contrast between a cool interior and hot outside conditions can put stress upon the body's physiology and can make people more susceptible to illness.

6.12.4 Indirect Impacts - Air Pollution

The impacts on exposure to air pollution are complex, as indicated below.

Table 6.4 Potential impacts of climate change on exposure to air pollution

Positive	Negative
Reduced exposure to damp conditions indoor due to being outdoors more often	Increased tropospheric (low-level) ozone (DoH 2002)
More circulation of air due to windows and doors being left open for longer	Dust mites survive for longer in drier air > asthma
If more outdoors lifestyles led to a more active lifestyle, then resistance to respiratory illness would probably be enhanced.	More dust raised in dry air > asthma

Note that most rooms have an air change rate of at least once per hour so that, chemically, most indoor environments will be similar to that outdoors plus internal sources (moisture, VOCs from plastics, smoke, etc.). Being outdoors more will not, therefore, contribute to greater exposure to air pollutants. Greater exposure to air pollution would occur at low level along major roads (including inside cars and buses) (e.g. see maps of London Health Commission, 2002). Hence, greater exposure under climate change would be limited to undertaking more journeys along major roads by car, bus, cycling or walking. More windy weather under climate change would, on the other hand, cause fewer air pollution episodes arising from the build-up of NOx, PM_{10}s, VOCs, etc.

People tend to eat more healthily in hotter and drier weather if the evidence of the hot summers of the mid-1990s is anything to go by, i.e. more fruit and vegetables (Palutikof et al. 1997). More active lifestyles on the part of children is to be desired given current trends towards obesity and lack of exercise. If better and hotter weather encouraged this, then there would be a benefit. If better weather was to improve the prospects of children walking or cycling to school more, then there would be the added benefit of alleviating traffic congestion during the ‘school run’ period. Likewise, if better quality and fresher fruit and vegetables were available under climate change, then benefits would arise, assuming that such foods are accessible. Unfortunately, there are already wide-spread variations in access to fresh foods in London. Whilst lower prices would help to make fresh foods more readily accessible, cultural change is also necessary.

What is more, measures taken to reduce the rate of climate change by reducing greenhouse gas emissions could produce secondary beneficial effects on health e.g. decreased dependence on motor transport could encourage walking and cycling - thus improving health. At the same time, 6.3 in 1000 pedestrians in London are injured in accidents (LHC 2002); over 8,500 pedestrians and 3,500 cyclists in 2000 (ibid.). Clearly, the greater use of bicycles and walking needs to be facilitated by taking steps to reduce the risks of accidents with vehicles. The risk is highest in the inner city boroughs of Westminster, Camden and Islington and least in the outer boroughs. Reducing the combustion of fossil fuels also limits the production of other pollutants such as SOx, NOx and particulates with potentially significant health benefits.

6.12.5 Case Study: Comparison with Other Cities

An intense summer drought in New York may have contributed to the fatal outbreak of the West Nile Virus (Rosenzweig & Solecki 2001a).

> *"Populations in such urban areas as New York City will experience increased exposure to heat stress conditions, greater potential of water-borne or vector-related disease outbreaks, and higher concentrations of secondary air pollutants, resulting in higher frequency of respiratory ailments and attacks (e.g. asthma)" (ibid: 9).*

With nearly a quarter of NYC's population below the official poverty line, the vulnerability of a large proportion of the population to adverse impacts, and inability to pay for air conditioning to relieve heat stress, is evident. Heat stress may increase by 2 to 7 times over the next century as the number of days over 90^{o}F (32°C) increases from 20 days per year to between 27 and 80 days per year during the 2090s. The Metro East Coast study also noted that:

> *"Heat waves will also exacerbate secondary air pollution problems in the region. Peak electricity demand and fossil fuel burning during heat waves will result in increases of primary air pollutants (e.g. nitrogen oxides) and secondary pollutants (e.g. ozone). Increased concentrations of such pollutants in turn will result in higher numbers of respiratory-related attacks and hospitalisations".*

It is not clear that increased peak electricity demand in London would have a comparable effect because most of London's electricity is imported rather than being locally generated. Hence, emissions of NOx and SOx associated with combustion will occur elsewhere, where they might have adverse health impacts. Flows of air into London from continental Europe might bring with it more pollutants, especially ozone, as a result of increased peak electricity due to a greater cooling requirement on the continent.

6.13 Historical and Cultural Legacy

The impacts of climate change on tourism and leisure are discussed with the other economic impacts in Section 9.

6.13.1 Context

London is a city rich in historical assets:

- 3 World Heritage Sites (Maritime Greenwich, Tower of London and Westminster Abbey/Palace of Westminster);
- 9,476 listed buildings;
- 123 historic buildings;
- 33 historic gardens;
- 149 scheduled ancient monuments;
- Large areas of the city are protected by conservation measures.

William Fitzstephen, Cockney-born monk of Canterbury, described Medieval London's "fields for pasture, and a delightful plain of meadow-land, interspersed with flowing streams, on which stand mills, whose clack is very pleasing to the ear. ….There are also around London, on the northern side … excellent springs; the water of which is sweet, clear and salubrious, mid glistening pebbles gliding playfully, amongst which Holywell, Clerkenwell and St. Clement's well are, of most note." (quoted in Fitter, 1945).

The little River Walbrook flowed openly through the City of London in the middle ages, entering the Thames at the dock of Dowgate. The River Fleet (or Holebourne) was large enough in medieval times to be navigable to Holborn Bridge. The Fleet then became notorious as an open sewer (Fitter 1945). These 'lost rivers' are now part of the underground sewerage system. Marshes and fenlands existed throughout London, e.g. Moorfields (site of Finsbury Square today) and much of the West End.

6.13.2 Flooding and Rainfall Intensity Impacts

Such histories are interesting insights into potential futures for London in a world of climate change. Is there opportunity to open-up culverted rivers and streams, or to re-establish wetlands? Do such water ways and wetlands provide clues regarding where future flooding might occur?

In addition to this, more stormy weather poses a threat to the integrity of buildings and may require higher expenditure on repairs and maintenance.

As for archaeological artefacts, the change in the flow patterns of the River Thames has already resulted in the un-covering of more extensive archaeological remnants. This is to be welcomed to the extent that it provides more archaeological evidence which can be used to illuminate the history of the city. On the other hand, however, the uncovering process potentially puts at risk the integrity and stability of the very remains which are so revealed. More resources may be required to protect such uncovered remains until such time as they can be stabilised and/or researched. Continued change in the flow patterns of the River Thames is likely due to sea-level rise, change in rainfall patterns and adaptation to such changes, e.g. operation of the Thames Barrier.

6.13.3 Temperature Change Impacts

More resources will probably be required to maintain the integrity of London's historic buildings and the materials contained therein. For example, internal temperature control will be an important requirement to protect delicate fabrics, furniture and furnishings.

Soil subsidence from drying out of clay soils could threaten the structural stability of older buildings. Historical buildings are much less readily adapted to climate change and there are likely to be planning and regulatory obstacles to any major structural or aesthetic modification. Hence, such buildings may be less adaptable and readily used than they are currently.

6.13.4 Socio-Economic Scenario Differences

Under GM, there is likely to be more building and re-development. This would result in potentially larger areas of historic London being uncovered and requiring investigation (or acceptance that this is not feasible). Under RS, there will be a slower pace of change and probably greater interest in the history of the city.

6.14 Clean City

6.14.1 Context

The MORI survey (2001) for the GLA on public perceptions of living in London revealed that air pollution was regarded as the second most serious problem for London out of a list of 8 environmental issues (63% of respondents regarding it as a problem, and 14% not regarding it as a problem). Furthermore, when asked whether London is a 'clean city', nearly three quarters of respondents disagreed, and only 19% agreed. Section 5 has illuminated some of the potential decreases in air quality for London arising from climate change. Given the high starting baseline of air pollution problems, that they may get worse given climate is of huge concern in terms of health and also for the image of London as an attractive place to live, work and visit. Natural ventilation approaches to cooling of buildings will be less attractive if there are higher levels of external air pollution, hence encouraging higher uptake of air conditioning, feeding-back to higher energy consumption and more urban waste heat.

6.14.2 Temperature Change Impacts

Household and commercial rubbish will decay more rapidly as a consequence of higher summer temperatures. This would increase the smell of rubbish, reducing the attractiveness of the city for its inhabitants and visitors. Changes in collection routines, with perhaps more frequent collections, might well be required. Hosing-down of streets is also likely to be required given hotter conditions, especially if there are higher levels of dust in the air, due to construction work or blowing in of dust from land. Yet, more street cleaning means more water consumption, putting greater stress upon limited water resources. The opportunities for utilising recycled waste water for street cleaning are evident.

6.14.3 Socio-Economic Scenario Differences

There could in fact be quite significant differences in air pollution arising between the two scenarios. One optimistic vision of Global Markets would see a transition to fuel cells, which would eventually replace the internal combustion (IC) engine. Fuel cells produce fewer noxious emissions. If hydrogen were the fuel of choice, then the principal by-product would be water vapour (with very limited emissions of other gases). If methane were the fuel used in the fuel cell, the emissions could (depending on the precise system) consist of by-products such as SOx and NOx. The greater efficiency of fuel cells compared to the internal combustion engine means that the actual emissions would be significantly lower than cars running on petrol (at least 50% lower per km). The wide-spread penetration of fuel cells in private cars, buses and even trains could have a significant benefit to the air quality in London, since much of the air pollution is currently related to use of the internal combustion engine. A less optimistic vision of GM, would not envisage replacement of the IC engine because less emphasis would be put on regulation of air pollution, reducing the incentive to develop fuel cell technology and associated infrastructure.

Under Regional Sustainability, we would see increased use of policy instruments at the city-scale to limit use of private cars, e.g. car zoning, charging schemes, availability of parking spaces, etc. There would be increased investment in public transport, especially buses (which are already used more heavily than elsewhere in the UK). One interesting aspect of the RS scenario is that we would not necessarily see a rapid development of fuel cell technology. This is because there would be less corporate investment in R&D internationally, because there would be a slow-down in the availability of capital in global markets.

6.15 Green and Open Spaces

6.15.1 Context

The quality and availability of parks and open spaces in London is well known. Indeed, this was mentioned as the *least* serious environmental problem in London in the MORI poll (2001), with 25% of respondents considering this to be a problem, but 49% respondents *not* considering this to a problem. On the other hand, when asked whether respondents considered London to be a 'green city', 55% disagreed, with another 37% agreeing.

6.15.2 Flooding and Rainfall Intensity Impacts

If open and green spaces such as land alongside the Thames are, in future, increasingly regarded as a potential flood water storage areas, then this multiple use of land would have implications for existing users. Using land as flood plains could also have effects upon the biodiversity value of such land (though these could be positive as well as negative). Access to parks and gardens might also be restricted in order to protect habitats and species which are threatened by climate change.

6.15.3 Wind Storm Impacts

Severe storms can have devastating effects upon trees. Richmond Park lost 10% of its trees in the storms of 1987 and 1990, but was relatively less affected than areas further south. Small stocks of veteran trees, as in Richmond Park, are especially vulnerable to extreme storms (Richards, pers.com.).

6.15.4 Temperature Change Impacts

As noted above (under housing) there would probably be greater demands put upon green and open spaces due to climate change. Any new development might need to ensure that there is explicit inclusion of open spaces. More localised open spaces are probably desirable, not just the large parks. Increased fire hazard would accompany hotter drier weather (especially hot dry springs and early summers). Such events are known, in many cases, to be caused deliberately by humans. Hence, not only are measures to detect fires more rapidly important, but also educational campaigns to dissuade those who might think of starting fires. Clearly, fires would have negative impacts for biodiversity, for access and for the amenity value of open-spaces, and adversely affect air pollution (as witnessed dramatically in Sydney in 2001). To deal with fires involves use of large amounts of water and this would add a further strain upon water resources, especially in hot dry conditions when fires are most likely.

The types of trees and other plants which will grow successfully will likely change in the future because of climate change. Already, the Royal Parks are observing that trees such as beech are not doing as well as they once were, though this may also be due to damage by grey squirrels (Richards, pers.com.). The London Plane tree (*Platanus acerifolia*) is probably rather better adapted to climate change, being a hybrid of the oriental and western plane, which grow in hotter climates, e.g. Mediterranean. The appearance of the Plane is quite different from the beech tree, however. An alternative would be Sweet Chestnut, which would perform equally well under hot and dry conditions, and supports a wider range of other species than Plane (Richards, pers.com.).

6.15.5 Socio-Economic Scenario Differences

Under GM, land use would be determined by the market, and there would be fewer restrictions of land for biodiversity and for amenity value than currently. High climate change impacts upon green spaces and its biodiversity would therefore be attenuated by the reduction in statutory protection and spatial extent of such land. By contrast, under RS there would be greater protection of land and more emphasis placed on enhancing and managing biodiversity. Under RS, the lower level of climate change plus greater protection of green spaces would be more favourable.

6.15.6 Case Study and Comparison with Other Cities

Case study of impacts on 'green spaces' - The Royal Botanic Gardens at Kew

The Botanic Gardens at Kew are famous as both a tourist attraction and a valuable centre for monitoring and conservation of flora and fauna. A former royal possession granted to the nation by Queen Victoria, it is now run as a non-departmental government body overseen by DEFRA. One of its statutory purposes is to conserve native flora and fauna, including species which come to live in the UK as a result of environmental change and conservation practice. Records at Kew have shown that some species (e.g. crocus, bluebells, laburnum and certain cherries) have been blooming earlier over recent years – roughly 1 to 2 weeks earlier since 1952. In 2002 the Crown Imperial Fritillary opened earlier than ever before. No records are kept of autumn leaf fall/turning.

Species such as Marbled White and Gatekeeper butterflies and certain types of rare dragonflies appear to be moving their range northwards, and more of these species are being noted at Kew. It is not clear if any species have yet been lost due to changing climate, but in the future drier summers may cause some plants to disappear. Species such as the meadow saxifrage (spring flowering in damp meadow habitat) and the wild camomile may be most at risk. However, even in the hot dry summers such as that of 1995 species reappeared after prolonged drought.

A warming climate would widen the range of species present, but lower summer rainfall with more evaporation would reduce the numbers. Emergency plans such as using river water or Kew lake water for irrigation are being considered, but there are health and environmental implications arising from such uses. For example, the Kew lakes and ponds are themselves important habitats and river water might need treating before it could be used. The satellite garden at Wakehurst Place, West Sussex (currently wetter and cooler) may be used as a backup.

Kew is on thin poor soil over gravel, with a high water table resulting in shallow root structures. Any raising of the water table from increased winter rain would cause even shallower rooting, paradoxically making plants more vulnerable to dry-out in drier summers. Direct flooding from the river has not been a problem yet, nor is salination of groundwater, but this may occur in the future with more overland flooding.

More visitors in a warmer climate would be welcome – in fact there are currently several initiatives to encourage more visitors such as seasonal festivals. Kew could accommodate a substantially larger number of visitors before it reached capacity. However, it is noted that in the very hottest weather the number of visitors falls, possibly due to the effort needed to get there by tube or car, or due to the relatively greater attractiveness of destinations such as the coast or countryside outside of London.

Comparison with Other Cities

New York City has an extensive amount of freshwater marshes (3000 acres, 2000 of which are on Staten Island) and 4000 acres of tidal wetland (Jamaica Bay). This, however, represents only a quarter of the wetland areas which at one time occurred in the New York city region. These coastal wetlands in New York are especially vulnerable to sea-level rise.

> *"Assuming that limited opportunity has been provided for a retreat inland, the remaining fringe of wetlands in the region would be in clear decline, causing a ripple of other ecological effects, including the loss of critical bird and aquatic habitats.*" *(Rosenzweig & Solecki 2001a:11).*

42% of the waterfront of New York City is city, federal or state parkland, including hundreds of acres of natural or undeveloped land, active recreational areas and narrow strips along highways and railways. There has been a tendency in the past to locate necessary, but locally unwanted, land uses on such marginal land (e.g. transport infrastructure and pipelines), so increasing the vulnerability of such assets to future sea water inundation. Land acquisition by the state government is a well established mechanism for the creation of 'greenways', habitat protection and consolidation of coastal properties. Recent purchases have not been in areas projected to be vulnerable to sea-level rise, but they do provide a model for future purchases as adaptations in areas vulnerable to global climate change.

6.16 Crime and Security

6.16.1 Context

The MORI (2001) survey of public perceptions of living in London found that 51% of respondents indicated that doing something about safety and crime was a top priority for London: this scored more highly than any other priority. London has a higher burglary rate than the UK average (at 9.5 incidents per 1000 people, totalling 70,200 in 2001), but the rate has been declining in line with national trends (though is anticipated to go back up in 2002) (LHC 2002). The burglary rate in Hackney and Lambeth is four times higher than it is in Havering and Sutton.

6.16.2 Flooding and Rainfall Intensity Impacts

Certain impacts of climate change have potentially major implications for the emergency services. The agencies involved include:

- The Environment Agency: which operates a system of flood warning. Following the floods on Autumn 2000 the EA published a report on the lessons learned and is taking forward action to improve responses to flooding;

- Health and medical services may be required to respond to human health impacts of climate e.g. illnesses associated with flooding and lack of clean water in extreme instances, asthma epidemics due to worsening air quality, possible increases in outbreaks of food poisoning from food spoiling in higher temperatures and heat stress victims due to an intensifying urban heat island;

- The Fire Brigade plays a critical role in responding to flooding, i.e. rescuing people and unblocking and clearing highways, pumping out water, dealing with fires caused by electrical storms and stabilising wind damaged buildings. This is important to allow medical assistance and to allow the fire service to respond effectively to other emergencies in the locality, such as fires. The floods of 2000 in other parts of the UK led to significant over-demand for the fire service, leading to major delays in crews getting to incident sites (Speakman, pers.com.). A severe flood in London on the 7th August 2002 resulted in 1,400 emergency calls to the London Fire Brigade in just 8 hours, one of the highest demands ever;

- Water and electricity utilities, which have a duty to restore services to dwellings as soon as feasible.

An important lesson from the 1998 and 2000 floods is the need for effective and well-orchestrated responses on the part of all the emergency services, including local and national government, the Environment Agency, the fire brigade, the medical services, and so on. It was found that a clear command centre is required at a suitable spatial scale (i.e. relative to the scale of the flooded catchment itself), which liases with lower-down local emergency response centres (Speakman, pers. comm.). A continued increase in weather-related emergencies will necessitate more resources being devoted to the emergency services.

An issue that needs to be addressed is the public's understanding of procedures following weather-related emergencies. This is an issue for emergency planning in general but climate change may contribute to an increased frequency of emergency events. Previously, many people's response to an emergency has been to seek shelter in the underground system. In a flood emergency such as failure of the Thames Barrier this would not be appropriate as the underground system may also be subject to flooding. Therefore there is a need for improved public communication on flooding, its consequences and flood warning. As mentioned above, the EA is carrying out a national scale project on communicating flood risk. A project is also planned on the socio-economic impacts of flooding. It would be helpful if this study examined the issues surrounding the public's response to climate change emergencies.

Previous research suggests that the EA's new categorisation of flood risks communicated via the media is clearer than the previous system, and also that its Floodline telephone service has been generally successful in providing information on request (Scottish Executive 2001). Where communities are well networked, there is likely to be a greater ability to respond to warnings and emergencies such as flooding, than in those communities which are highly fragmented. In general, more affluent communities are better able to respond effectively to emergencies than poorer communities. Better networked communities are more able to look after the interests of those who are relatively worse-off and isolated or who have more dependants, e.g. the elderly, single parents, large families, etc. This difference in the ability of communities to respond to extreme events could also be used in the formulation of emergency service response strategies, through targeting the most vulnerable (i.e. less affluent and more fragmented) communities first (Shackley et al. 2001, Scottish Executive 2001).

An integral part of the Environment Agency's Flood Warning service is to produce a London Flood Warning Plan for fluvial flooding. A workshop is held each year with its professional partners to review this plan and ensure the details provided take account of recent flooding.

Local meetings are held regularly with Emergency Planning Officers from the local authorities to discuss specific issues relating to flood risk areas. Exercises are held each year for those agencies responding to flooding emergencies. These exercises provide the opportunity to review and confirm procedures based on flooding scenarios. A close relationship is maintained between the EA and its professional partners through joint public awareness initiatives, local flooding workshops and regular emergency planning meetings. The last update of the London Flood Warning Plan was two years ago and an updated version is being produced. The Plan is reviewed annually and will be updated as appropriate in future based on the impact of climate change.

The legislation and funding of local emergency planning is currently being reviewed by the Home Office/Cabinet Office, with a view to ensuring that responses to all emergencies, including flooding, are fast and effective. The Office of the Deputy Prime Minister (formerly DTLR) is also reviewing the Bellwin Scheme which is a means for local authorities to obtain financial assistance in clearing up immediately after a local disaster or emergency. Adaptations were made to the system in October 2000 in recognition of the exceptionally high number of flooding incidents requiring activation of the scheme. A review group has been set up to take full account of the operation of the scheme following the autumn 2000 floods. As part of this general review of funding, the GLA and London local authorities should assess the possible impacts of climate related emergencies on funding requirements.

6.16.3 Temperature Change Impacts

Certain impacts of climate change have potentially major implications for the emergency services. The agencies involved include the fire service, police, local authorities, health services and the Environment Agency. An increased risk of fire from drier, hotter conditions may require action by the London Fire Brigade.

In addition to the direct threat to the safety of individuals and their property from floods and extreme winds and so on, there is also the risk that disruption might render some systems more susceptible to crime. (Looting of shops has accompanied natural disasters such as earthquakes in some cities in the USA). The possible increase in crime from more open doors and windows in a hotter climate has already been discussed under housing. There is some evidence of a relationship between hotter weather and traffic accidents, but the data is not very applicable to the situation in London.

There have been several controversial theories in the past which have linked unusually hot weather with more risk of public disorder. The most extreme idea of ‘weather determinism’, suggested that hot weather events could actually *produce* public disorder, though most commentators have discredited such ideas which fail to take account of the underlying structural and economic reasons why discontent exists (Shackley & Wynne 1994). A more moderate suggestion is that exceptionally hot and humid weather would be more likely to encourage certain types of anti-social behaviour amongst certain individuals who were already pre-disposed to such behaviour patterns. However, adaptation and acclimatisation is likely to occur, judging on the record of other societies which already exist in hotter climates. Underlying socio-economic, cultural and political conditions are widely considered to be much more important determinants of crime and disorder.

6.16.4 Indirect Impacts to Crime and Security

The high cost of housing in London is already having a serious impact upon the ability of 'key workers' in the public sector such as teachers, social workers, local government, health workers, fire and ambulance emergency-services, etc. to live and work in the capital. The fact that many such posts are currently unfilled means that the ability of London's emergency services to respond effectively and rapidly to climate change-induced emergencies and disasters is likely to be impaired. This could have a very significant effect upon the damages to humans and property, and the level of disruption, associated with events such as heat waves, floods, water shortages, etc. since the impact is tightly coupled to the level and effectiveness of response.

Evacuation of people from their homes into temporary communal emergency centres which may occur due to a climate related emergency is not only stressful to many, but may also encourage crime and anti-social behaviour to emerge amongst some of the temporary occupants. Property and possessions are especially open to theft in such circumstances and the fragmentation of communities means that there is frequently no pre-existing 'social network' to help manage such situations. Community development professionals and social workers might play an important role in assisting such temporary communities.

If climate change led to more outdoors drinking of alcohol in pubs and bars, as presently occurs on hot days in spring and summer now, there could also be a knock-on effect in terms of violence and anti-social behaviour, and possibly drink-driving, with associated accidents. Adaptation to 'hot' weather is likely, however, such that hot sunny days cease to be anything exceptional and therefore not *per se* a reason to 'go for a drink' (which they presently are for some).

If the attractiveness of London were to decline as a consequence of climate change, then economic conditions might deteriorate, creating the conditions in which crime and disorder would grow. Much would depend, however, on the distribution of wealth and other socio-political policies and programmes.

It may be necessary for the public to utilise public buildings which have air cooling systems in the case of a heat wave, or in case of a severe flood event. In Toronto, there have recently been three heat waves during which public buildings with AC have been open to members of the public who are becoming heat-stressed. This sort of emergency public service provision is relatively novel in the UK, but procedures for the utilisation of public or even private-sector infrastructure may be necessary in the future to cope with climate change-induced extreme events.

6.17 Towards Analysis of Feedback Processes

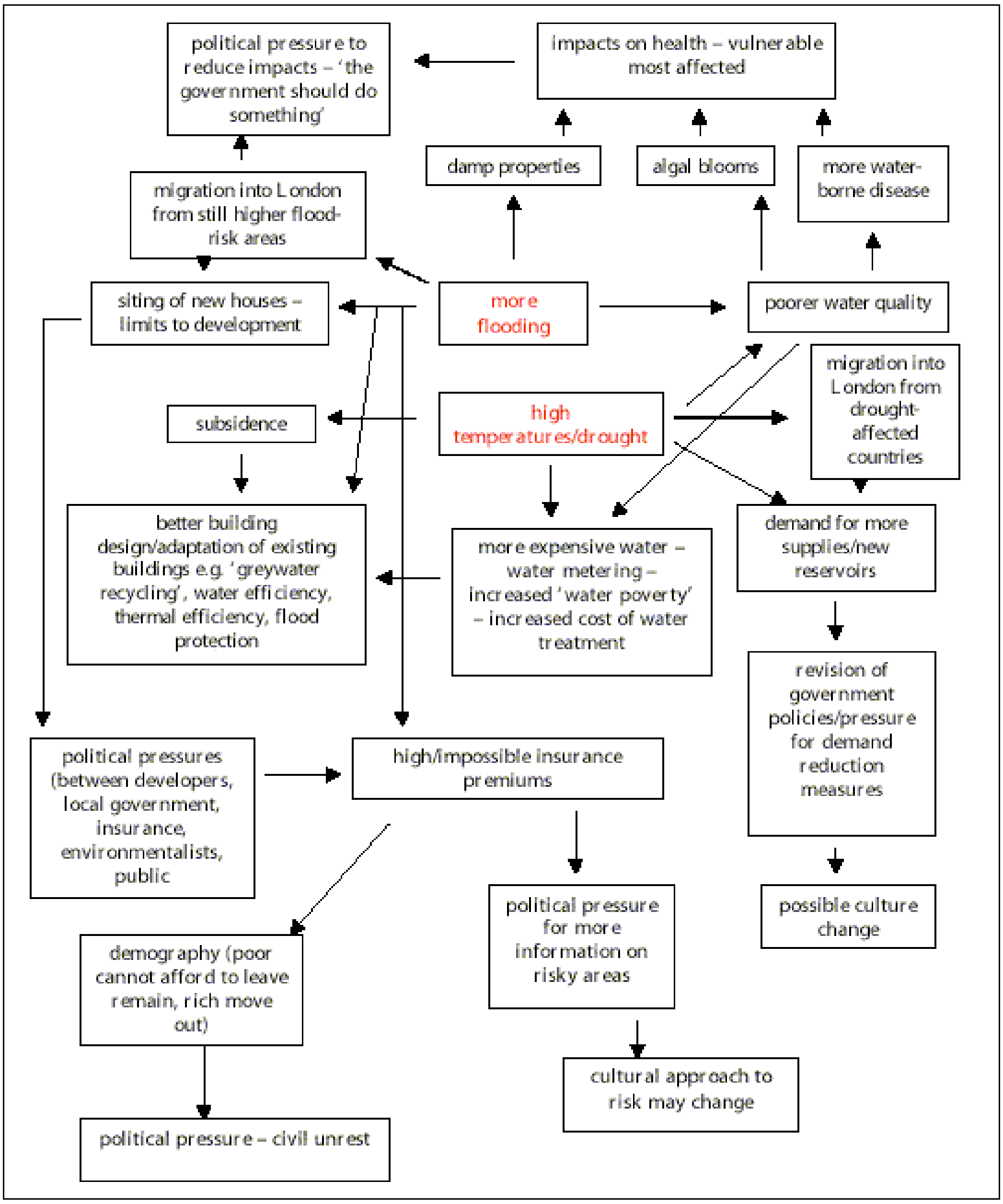
In many of the preceding discussions we have described *feedbacks* between climate impacts and social and economic aspects of life. These are multiple links between different aspects of climate change (such as increased frequency of hot days or increased winter rainfall) and their consequences. Analysis of these feedback processes is important because the complex interplay between climate change impacts and adaptation measures can sometimes produce results unexpected from a simple analysis. In this study we have only skimmed the surface of assessing feedbacks within a system as complex as how London may respond to climate change. To demonstrate some of the complexity involved, we now present an example from the second workshop in which we examined interactions between three key areas – demography, high temperatures and increased flooding. We identified two classes of feedbacks:

i) those between social, economic, environmental impacts **within** each different aspect of climate change e.g. hot days -> poor air quality -> health goes down (*social impact*) -> worker productivity goes down (*economic impact)*

ii) those **across** different aspects of climate change: e.g. hot days -> poor air quality -> health goes down (*social impact*) -> people move out (*demography*) -> fewer new houses needed on flood plain -> impacts of flooding are reduced (*social and environmental impacts*)

Both types of feedbacks are represented in the resulting diagram (Figure 6.5). The direct changes in climate are highlighted in red and the consequences follow along the links chains. Note especially the bold highlighting of the social, cultural and political impacts of climate change.

Figure 6.5 An example of the feedbacks between different impacts of climate change. Bold text highlights social, political and cultural consequences.



6.18 Summary and Conclusions

To summarise the discussions in this Section, we return to the concept of attractiveness introduced in Part 1. For each section, we made an overall assessment of how climate change is likely to alter the attractiveness of London, and our conclusions are summarised in Table 6.5. It is important to note that it is a qualitative judgement based on the material presented in this section and the discussions which lie behind it, and the experience of the research team. It should not be taken as more than a first and very tentative attempt to evaluate impacts. The largest difference of opinion within the research team itself concerned the impacts of climate change upon green and open spaces: according to the more optimistic view point climate change would result in an increase in such space as an adaptation measure; whereas this would not occur to the same extent in the more pessimistic view.

The summary table does indicate that on balance the social impacts of climate change upon London are perhaps somewhat more negative than positive. There are, however, some potentially significant benefits for a number of sectors such as tourism and leisure. We have also identified some fairly small benefits for a number of additional sectors including transport, housing, historical and cultural legacy, jobs, health and so on. The larger negative climate change impacts for housing, redevelopment, built environment, health, clean city, cost of living and open and green spaces are all highly uncertain, in part because the scale and precise character of the impact depends on the adjustment and adaptation responses. Most of the larger negatives are attributable to potentially increased flooding, greater incidence of summer heat waves, exacerbation of existing air pollution problems and increased pressures upon open and green spaces. Clearly, suitable adaptation policies and management could limit the incidence of the most negative impacts. A further factor in our assessment is that many of the potentially positive impacts of climate change are somewhat intangible and highly distributed across society. Some of the largest potential negative impacts are more highly concentrated in their distribution, e.g. flood risk, and this can make them appear to be more significant. Compared to the other regional studies of climate change impacts in the UK, there are some significant differences, but also some interesting similarities.

- It is interesting to note that the pattern of 'pluses' and 'minuses' in the summary table are rather similar to the pattern obtained in other regional studies (available at www.ukcip.org.uk).

- The main differences in assessment arise because the area covered by Greater London is much smaller than the other 8 English regions, and does not include anywhere near the same amount of open countryside. Hence, the knock-on social impacts arising from the effects of climate change upon agriculture, large biodiversity resources, long stretches of coastline, and so on, do not apply to the same extent in the London case. The high population density in London (twice that of most other UK cities) and the exceptionally strong growth and population pressures upon the city, and its role as a global city, all serve to make the London study a 'special case'.

- The impacts on London will also spill-over in important ways and come to affect the South East and East of England regions (as well as further afield), especially for recreational and leisure purposes. Yet, the pressures from climate change upon the coastline and other beauty spots in the South East are considerable, as indicated in its 1999 climate impacts study (Wade, et al. 1999).

- Climate change impacts on transport, buildings & built environment, parks & gardens, air pollution, tourism, and so on, are all exacerbated in London compared to other cities and regions, because of the strong pressures already being exerted upon these systems and sectors.

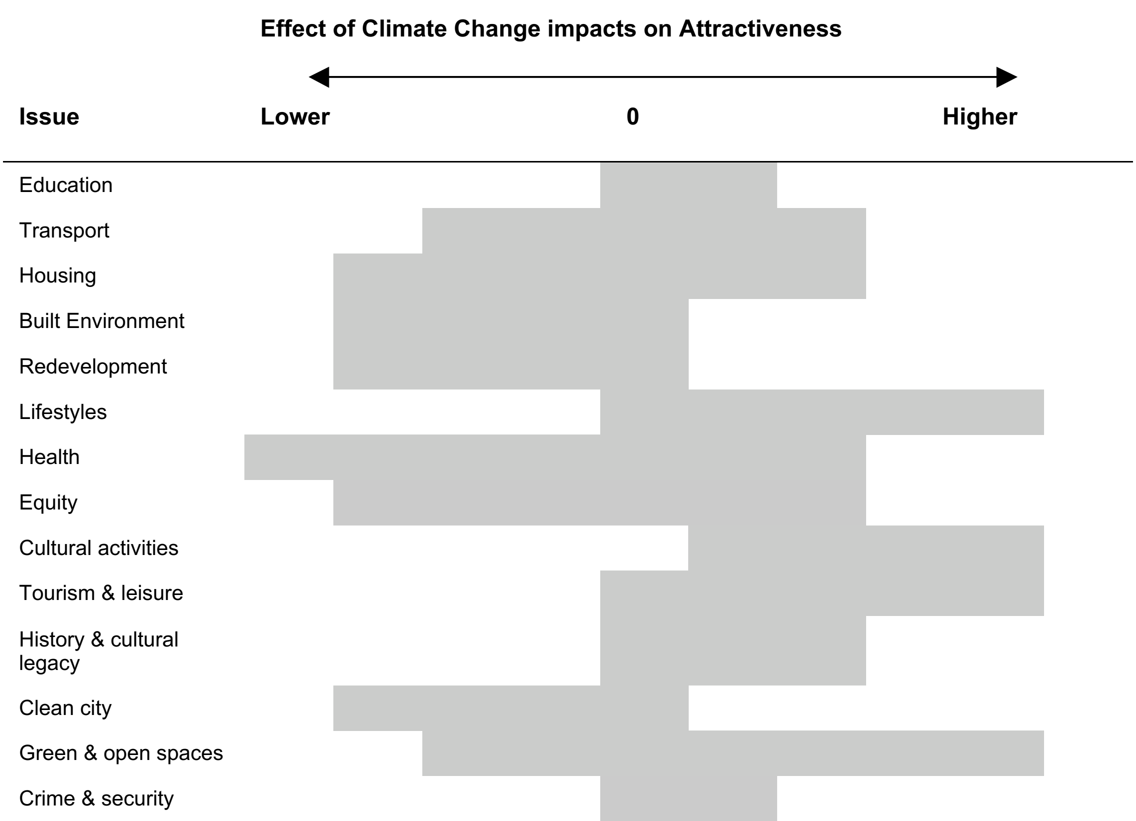
- Whilst climate change is, potentially, an opportunity for the built environment and redevelopment (or at least can be tackled through use of natural ventilation) in other parts of the UK, it is more difficult (whilst not impossible) to see the 'silver lining' in the case of London. This is because of the higher baseline temperature in London, the urban heat island effect and the very high pressure for new housing and new commercial development.

- The draft London Plan argues that it is most appropriate to compare London to other global cities such as New York, Tokyo, Paris, Berlin and so on. The very preliminary comparison of climate change impacts in Tokyo and New York, suggests that the adverse effects in those competitor cities would be slighter greater than in London, at least in the current socio-economic conditions.

- Impacts upon other comparative European cities have not been evaluated. London starts from a cooler climatic baseline than most continental cities, however, and will continue to be cooler than cities further south in a situation of climate change. Provided that necessary adaptations can take place, then London will perhaps fare better under future climate change than competitor cities in many other parts of central and southern Europe.

- The most robust conclusion to draw is that a preliminary comparison between competitor cities indicates that London does not face any significantly greater adverse or beneficial impacts than other cities. A more robust comparison between impacts on global cities is an important future research task.

Table 6.5 Summary of the effect upon London's 'attractiveness' of climate change impacts on different systems and sectors. 'Lower', for example, indicates London becomes less attractive from the perspective of that sector under climate change



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7. The Potential Economic Impacts of Climate Change in London

7.1 Introduction

London's role in the UK and international economy ensures that any climate change impacts on its economy are likely to have significance in terms of economic multiplier effects elsewhere - see Box 1. This section of the report identifies and evaluates the importance of potential climate change impacts on economic resources and economic activity in the city. We take as our starting point in this exercise the findings of the previous sections of climate change scenarios for London and the associated environmental and social impacts.

Furthermore, the socio-economic scenarios described in the preceding section are shown below to be important in determining the likely severity of the economic impacts in the future.

It has been agreed with the LCCP that it is most useful to consider economic impacts in terms of their sectoral classification. Thus, we adopt the sectoral classification suggested by the project Steering Group to include the most likely significant sectors in determining the future economic prosperity of London. These sectors are:

- Tourism and leisure;
- Insurance/financial businesses;
- Manufacturing industries;
- Public administration;
- Creative industries;
- Environmental businesses.

Consideration of these sectors will be in parallel with the cross-sectoral elements likely to be impacted by climate change in London. Foremost amongst these are: transport; energy and labour supply. Clearly, impacts on these (e.g. transport disruption due to flooding) will have consequent impacts on economic activities (e.g. disruption to freight) and these linkages are traced. A detailed analysis and evaluation of possible adaptation strategies is likely to be undertaken in phase 2 of this project.

London's present status as a world city rests largely on the fact that it supports a substantial concentration of economic activities that are critical to the global economy, principally including the financial services sector and its linkages with global trade and commerce. The potential impacts of climate change on this status are considered - relative to other competing world cities such as New York or Tokyo.

Box 1 A profile of the economy of London in relation to climate change

Greater London has an estimated GDP of £168.6 billion, and accounts for 20.3% of the UK GDP. This economic activity supports a workforce of 3.5 million, 32% of which are in business and financial services, 19% in the public sector , 16% in retail, 7% in manufacturing, 6% hotels and restaurants. It is estimated that London 'imported' from the rest of the UK £89 billion of goods in 1998 - supporting 4.7 million jobs outside the capital.

The title of Global City derives from the fact that it is one of the three largest financial centres in the world (alongside New York and Tokyo) and has the largest share of trading in many financial markets, including foreign exchange of which it controls 36% of the global turnover. The City of London has a GDP of £22 billion - equivalent to 2.6% of the UK GDP.

Manufacturing in London is responsible for 300,000 jobs (7% of the capital's workforce) and £11 billion output. The creative industries, including theatres/cinemas, contribute £7 billion to the UK's GDP, whilst the city also has the characteristics of a knowledge economy, being a centre of academic excellence and providing research and consulting services throughout the world.

Box 1 presents an overview of the London economy. It demonstrates that whilst the economy of London is pivotal to the UK, and perhaps, global, economy, it is by its nature therefore heavily inter-dependent on the national and global economies. Any impacts on London of climate change are therefore likely to have significant wider implications. At the same time, climate change impacts of perhaps greater magnitude elsewhere in the world are likely to be felt in the economy of London. The purpose of this section is to provide a first assessment of the extent of these potential impacts.

7.2 Outline of Methodology

This section is compiled from the output of two work phases within the project. These two phases are: the Review Phase and the Consultation Phase. The Review Phase has surveyed available literature in order to establish i) the way in which economic activities undertaken by the private and public sectors might be expected to be impacted directly by climate change in London, and ii) how climate change impacts in other parts of the world may impact on the economic activities in these sectors in London.

The section is divided in the following way. First, climate change impacts associated with the key sectors that have direct cross-sectoral roles - transport, energy and labour - are identified, described, assessed in terms of their possible severity, and their amenability to adaptation. Following this, the financial services, insurance, manufacturing, public administration, tourist/creative, environmental business sectors are considered in the same way. There is then an assessment of the possible consequences for economic development of climate change. Comparative analysis with other large cities is undertaken where possible and global climate change linkages are identified and assessed.

In the case of each sector considered, a summary table is provided that shows:

Climate change variables and associated impacts
The climate change variables that are presented are crude characterisations of the variables quantified in detail over the different time horizons in the scenarios presented in Section 4. It was found in the course of the stakeholder consultation that these characterisations were more useful in eliciting responses as to possible types of impacts. The impacts themselves are rough encapsulations of the principal impacts described in the main body of text.

Intra-sectoral severity ranking of economic impacts
The climate change impacts presented in each summary table are given a weighting (H = High; M = Medium; L = Low) according to the perceived severity of the impact on the economic health of the sector. Where it has not been possible to use a sectoral stakeholder perception (e.g. in the case of transport) the project team has made a judgement on the severity ranking.

Employment effects associated with impacts
Adopting the principle used in making the severity ranking, the assessment of employment effects is with regard to the level of employment presently in the industry. It is not therefore an assessment of the net employment effect in the economy. It should be emphasised that most of the employment effects identified are *diversionary,* or represent *transfer,* within the economy, rather than creating new jobs. Again, where it has not been possible to use a sectoral stakeholder perception the project team has made a judgement on the severity of the employment effect.

Uncertainty rating
Working Group II of the IPCC Third Assessment Report (IPCC, 2001) provides a detailed rating scale for the degree of uncertainty that is currently attached to specific climate change impacts globally. We have simplified this rating scale to High, Medium and Low, but present the broad sectoral rating made by Working Group II for the impact identified for London.

Sensitivity to socio-economic scenarios
The socio-economic scenarios are identified in Section 6. Where possible, we have indicated how each economic impact is likely to be determined by the two different scenarios: Global Markets (GM), and Regional Sustainability (RS).

Key non climate change sectoral drivers of change
In recognition of the fact that climate change impacts need to be considered in the context of how the sector is changing more generally, we highlight the principal drivers currently behind such change. This information should be seen as background information needed to develop a subsequent adaptation strategy for the sector.

Key stakeholders in impact and adaptation analysis
Identification of key stakeholders is also a prerequisite for looking to develop a subsequent adaptation strategy for the sector. Before developing such a strategy one would clearly conduct a full stakeholder analysis that maps the relations between primary and secondary stakeholders. This is a first task for phase 2 of the current project.

In the final column in the table (‘current availability of adaptation options’):

- ‘Y’ indicates that adaptation options have been identified by stakeholders to reduce climate change impacts. They are currently being considered for inclusion in general sectoral development strategies.
- ‘N’ denotes the fact that options either have not been identified, or are not being considered in strategy development.
- ‘-’ denotes that it is inapplicable i.e. the impact identified is a beneficial one.
- ‘*’ denotes the net effect is indeterminate.

There is then presented a brief overall summary of economic impacts on London.

7.3 Transport

7.3.1 Context

London is a national and international transport hub for road, rail, air and shipping in addition to supporting movements within the city. Each working day 466,000 peak period commuters come into the city centre and 7 million walking trips are made. It is therefore critical to the effective workings of the city’s economy. The Mayor’s Transport Strategy[1] for London notes, though, that whilst the city has “seen two decades of rising population and a decade of expanding economic growth and employment, this growth has not been matched by the investment necessary to provide the public transport, affordable housing and public services that are essential for economic efficiency and the wellbeing of London’s population”.

The Strategy document goes onto say that there is therefore “a growing crisis on London’s transport system – with some roads approaching gridlock and severe overcrowding, discomfort, unreliability and equipment failures on the Underground and National Rail network”. The Strategy therefore envisages a significant expansion and improvement in public transport provision in London, including cross London rail links, three new river crossings in and around London, the completion of the Channel Tunnel rail link and substantially increased capacity at airports in the eastern half of the metropolitan area.

Against this background, the stakeholder consultation suggests that the following types of impact on London’s transport system may be most significant:

- Disruption to transport modes from flooding and other extreme weather events;
- Changes in the types of journey taken e.g. if summer heat island effects have significant impacts on the willingness to commute into central London;
- Switches between transport modes as a result of changing travel conditions.

These impacts are explored in more detail below, on a transport mode basis. We then draw together conclusions as to how climate change may impact on the operation of the existing transport strategy.

[1] http://www.london.gov.uk/approot/mayor/strategies/transport/index.jsp

7.3.2 Rail Transport

Context

There exists a dense and extensive network of rail track in and around the Greater London area - extending across the UK - that supports business, commuter and leisure travel in London.

Stakeholder consultation with sectoral representatives has borne out the general perception that the rail network is climate sensitive and has vulnerabilities associated with climate change. These are identified below.

Flooding and Rainfall Intensity Impacts

Clay shrinkage impacts upon structures on which the rail network is reliant, including bridges, tunnels, embankments and cuttings. Therefore more reinforcement is necessary if an increasing rate of disruptions is not to be expected. Land-slips may result for the same reason, if higher winter rainfall intensities lead to increased instability in banking and slopes. A change of this type has already been noticed in other parts of the UK e.g. South Scotland.

Flooding when drainage systems cannot cope. Water on the rails acts as a conductor for the electricity in the rails and therefore its presence mimics the presence of a train at that location. Consequently, the network control systems need to send engineers to such locations in order to check what is happening. This checking process therefore results in delays to those trains that are using the track. Bridge scour when high levels of river water, combined with debris, works at the foundations of bridges. This reduces their stability and requires preventative expenditure. It also results in disruption to the network when bridges are closed.

Flooding would cause disruption and reduce the mobility of Londoners, and cause knock-on impacts through out the city. A recent example of the impact on flooding was on the 7th August 2002 when five of London's mainline stations were closed due to floods after intensive rainfall. Travel within the capital, and into and out of the capital, was seriously affected by these floods.

The most vulnerable areas are those which are located in the flood plain of the Thames and its tributaries (such as the Rivers Lee and Wandle). Areas of flood vulnerability are currently the subject of targeted investment in flood mitigation schemes. High risk flood areas, such as those associated with surface water drainage failure and shallow groundwater flooding, can also be outside the flood plain.

Temperature Change Impacts

Direct sunlight accompanied by summer heat can causes 'hot rails' to buckle. The imposition of speed restrictions in this situation is in order to mitigate the risk of buckling. In order to avoid this, the rails need to be de-stressed which is a manual practice. The problem is most likely to occur when there are rapid temperature changes between night and day and in extremely hot weather.

Point heaters are used to ensure that points remain functioning in freezing conditions. It is expected with the warmer winters predicted in the climate change scenarios that these point heaters are likely to have to be used less often. There are therefore less likely to be technical difficulties with the operation of these heaters, and less subsequent delays.

Impacts Due to Wind Storms

Lightning can damage integral parts of rail infrastructure including signalling equipment and telecommunications since, whilst some surge protection exists, it is not presently 100% reliable.

Leaves are a major problem in autumn when compacted into mulch on the rails since they result in braking and traction problems. There may be higher likelihood of the mulch being created as a result of climate change. Six key species are: Sycamore, Small Leaf Lime, Black Poplar, Horse Chestnut/Sweet Chestnut, Ash and Beech – the latter where leaf fall is in high quantities. It has not yet been established by the project team as to whether climate change is likely to result in greater growth and expansion of these species.

Wind affects overhead lines e.g. on the East Coast line from London, and some suburban routes in the Greater London area. Fallen trees that block the train line are likely to cause similar disruptions in the future if storm intensities increase.

General Climate Change Impacts

The issues identified above clearly affect the efficiency of the Channel Tunnel transport link to continental Europe. If these issues are perceived by international business travellers who use this link as significantly increasing the time unpredictability of the journey, this is likely to reduce the attractiveness of London as a business centre relative to other European cities - assuming no adaptation measures are implemented in response.

7.3.3 Case Study

The case study below, presents a costing of an historical analogue of a potential future climate change event - flooding of a commuter train line to London Paddington railway station The methodology is that developed for UKCIP (UKCIP, 2002). As explained in the introduction to this section, any costing exercise performed on an historical analogue should not be interpreted as a prediction of future climate change impact costs.

This case study uses evidence supplied by Railtrack on the extent of disruption to rail services caused by flooding to a rail line. The costs estimated below relate to: i) the time lost due to flooding at Stroud's Bridge, on the rail link between Oxford and London between 13th and 18th December, 2000. The disruption of rail services is measured by the number of minutes by which each train is delayed, having reached its final destination. In this case, the total number of minutes lost (calculated by multiplying the delay to each train by the number of delayed trains) has been estimated to be 22,338. The appropriate economic unit values we adopt here are taken to be £55/minute delay (based on the Strategic Rail Authority's (SRAs) official average rate, charged to Railtrack). These values are then multiplied by the 22,338 minutes lost, as identified above, to give estimates of the economic costs to Railtrack. It should be emphasised that the estimates presented below do not include the infrastructure repair costs which the flood damage necessitates. The cost estimates also do not include the value of lost time suffered by train passengers as a result of the disruption since the data needed to make estimates of these economic cost elements is not currently available. However, it is likely that these cost elements would be comparable to - if not significantly greater than - the costs presented below.

Table 7.1 Total Cost of rail network disruption: Stroud's Bridge, Oxfordshire

Total time loss (minutes)	Unit value (£/minute)	Total value (£)
22,338	55	1,228,590

Clearly, since this track represents a major commuter line to London, much of this disruption cost is likely to be borne by London's economy. It should be emphasised that these estimates are for one track flooding estimate only. It is likely that the floods of November and December 2000 resulted in an economic cost from disruptions on the rail system as a multiple of this value.

Investment measures needed to bring about **adaptation** of the rail network to counteract the type of potential climate change impacts identified here can currently only by funding that requires the submission of cash requirements on a five-yearly basis to the Office of the Rail Regulator and the Strategic Rail Authority.

7.3.4 The London Underground Rail System

Flooding and Rainfall Intensity Impacts

Similar economic consequences are likely to result from possible flooding incidents that may result from inundation of water either from overflowing drains or from one of the London rivers as a consequence of a high intensity rain event identified by the climate change scenarios. The consequence of such an event would be disruption of tube services and the resulting loss in time to businesses as personnel are delayed. The possibility of a flood event may be exacerbated by the rising water levels that some parts of the city are presently experiencing.

The risk of flooding in the Tube system is a major and urgent one, and is being taken very seriously by London Underground Ltd. The extent of the problem was revealed on 7th August 2002, when intensive rainfall led to flooding of a number of tunnels and closure of stations and parts of the network, including Chalk Farm, Kentish Town, Belsize Park and Wandsworth. The amounts of water entering tunnels, either from groundwater seepage or flooding from the surface, have been increasing but no figures for amounts are available. There are well-established procedures in place to deal with pumping water from tunnels, including a combined water pumping strategy, in which groundwater surrounding the tunnels is pumped via boreholes to local water courses, preventing water from entering the tunnels at all. Such pumping does raise the risk of the pumped water being replaced by saline water intrusion. Many lines have flood gates to prevent water entering stations.

A detailed 25-year plan showing the risks of flooding to different parts of the system also exists, but is currently confidential. Maps have been designed indicating the likely timings of impacts resulting from an overtopping of river walls.

Temperature Change Impacts

Stakeholder consultations identified that extreme weather events were likely to be the principal way in which climate change impacted directly on the London Underground train system. In particular it was suggested that a tendency towards more very warm days during the summer months would result in increased discomfort in travel in the underground where there is little air circulation.

High temperatures have been regularly experienced by passengers in hot weather on the underground, e.g. with reports of temperatures having reached 40°C in one instance. The health implications of this are potentially highly serious. Interestingly, however, hot spells produce no decline in number of travellers. The London Underground Ltd. (LUL) has examined the possibility of installing air conditioning but has indicated that this is not a practicable option. The reason is that the Underground was not designed with AC in mind and there is not enough space within the tunnels for additional AC units to be attached to carriages. The London Underground is the oldest in the world, dating back to 1863, and only in the most recent systems, such as those in Hong Kong and Singapore, has AC been employed. Even in these more modern systems, however, a problem has emerged of what to do with the waste heat displaced by AC. Because of the energy consumed in the AC unit itself, there is more heat to deal with than without AC. The waste heat would probably build up in the tunnels and platform areas, becoming unpleasant and a fire hazard. New stock on the Jubilee, Northern and Central lines have, however, recently been installed with forced air pressure ventilation systems. These operate automatically when certain temperature and humidity thresholds are reached. The main part of the network relies upon natural ventilation through the windows at the end of each carriage.

An interesting adjustment response to high underground temperatures by LUL in July 2001 was to distribute cold bottles of mineral water to all passengers at selected stations, e.g. Oxford Street and Piccadilly Circus. Other potential strategies include using water pumped from tunnels as a coolant, and several collaborative projects with universities are trying to deliver 'cool, clean air' into the Underground. The infrastructural costs of installing water-based heat exchanges would, presumably, be high.

General Climate Change Impacts
An indirect effect of the occurrence of these type of events may be to encourage both businesses and individuals to review their current working patterns and location decisions. One stakeholder commented that "it only needs a couple of consecutive very hot summers for people to commit themselves to working at home more, or relocating out of town". Businesses may therefore be forced to follow suit in order to retain a qualified or experienced work force, assuming there is a sufficient pool of labour in the new location (e.g. M4 corridor).

7.3.5 Water Transport

Context
Both the Thames and several of its tributaries (e.g. Deptford Creek, Barking Creek) are used for commercial and recreational shipping, but the largest freight ships go to Tilbury Docks (operated by the Port of London Authority or PLA) in Essex rather than into London. Navigation along the tidal Thames, and its navigable tributaries, is the responsibility of PLA. The PLA still handle about 10.5 million tonnes of cargo in and out of London a year. The River Thames is also used to move 750,000 tonnes of waste each year, which eliminates the need for 59,000 lorry journeys. The PLA is beginning to address the potential impacts of climate change, and is involved in the Environment Agency study on flood risk management in the Thames Estuary (EA 2002). The PLA has not yet encountered any problems arising from sea-level change. The Mayor's Transport Strategy notes that the River Thames in London presently

provides transport for 3 million journeys each year - either for leisure or commuting purposes. The Strategy is looking to promote both aspects of river use.

Flooding and Rainfall Intensity Impacts

Both passenger and freight movements on the Thames (tidal and non-tidal) and the city's canals may, however, be jeopardised either by low flows that might, for example, accompany low summer rainfall, or by high flows resulting from higher intensity rainfall events. Both climate change-related events are suggested as threatening the navigability of the river. The 1976 drought provides a possible analogue for the first event possibility. In this case, the Thames was threatened with total closure for any forms of traffic. It had significant impacts on the supplies of raw materials for manufacturing and food products. Whilst the air freight system is now likely to better cope with any equivalent event for food products, water transport remains essential for bulk freight shipments. There may therefore be a significant disruption in international trade links in raw materials for manufacturing and food products, and the domestic industries that use these materials.

Operation of the Thames barrier blocks off shipping. More frequent operation of the barrier in recent years has not compromised the viability of upstream docks, however. This is because there is always at least one point in the day (i.e. low tide) when the barrier is open (even when the barrier is operational) so some shipping can get through (although at low tide the larger ships may not pass). However, much more frequent closure of the Thames Barrier, and the construction of new barriers to combat future flood levels, may cut some areas off for docking in the future. Inundation of docks may be a problem if both riverine flooding and sea level rise contribute to rising river levels both up and downstream of the barrier.

With a more explicit strategy of using the estuary upstream or downstream of the Barrier for water storage as an adaptation to climate change, e.g. during high tides or during periods of high rainfall, then flooding of docks might increase. The draft London Plan includes the suggestion that more freight could be handled using the River Thames and observes that there are 29 protected wharves between Wandsworth/Hammersmith and Greenwich/Newham. It also notes the potential for freight operations on the Lee Navigation and the Grand Union canals (GLA 2002a). Clearly, the vulnerability of such water-based freight to a change in rainfall patterns and more frequent use of the Thames Barrier requires investigation as part of the development of the freight strategy.

Indirect Effects

River service disruption may act as a disincentive to potential tourist visits to the city from overseas, though it is thought likely to change the length of stay in London rather than resulting in a switch to an alternative destination.

Most of the 3 million a year boat journeys are for leisure purposes but with extensive development in the Thames Gateway, it is likely that there would be enhanced demand for travel along the river as a pleasant alternative to busy terrestrial routes. Some of London's canals could even potentially be used for this purpose, as happens in, e.g., Amsterdam. There is existing empirical evidence that the London Thames does act to cool the air in areas adjacent to the river (Graves et al, 2001).

7.3.6 Road Transport

Context
The Mayor's Strategy notes that high car use rates in London currently ensures that the city experiences high levels of road congestion - and therefore lost time - on a daily basis.

Flooding and Rainfall Intensity Impacts
Climate change impacts on use of road transport are suggested to include travel disruption due to flooding incidents on vulnerable stretches of road, resulting from high rain intensity events.

Temperature Change Impacts
Buckling of road surfaces may occur in spells of hot weather during summer months. This was the case of the historical analogue of summer 1995 when asphalt roads were subject to 'bleeding' and 'fatting up' due to the binder materials melting and resulting in road rutting. Indeed as a result of this event, the British Standard specification for road surfacing performance was amended (Palutikof (ed.) 1997). It is not known whether the revised specification will be adequate for future climate change related hot days.

The 1995 analogue also provides evidence that car use (and indeed rail use) for leisure is positively related to spells of warmer weather. Participants in the stakeholder workshop also felt strongly that alternative forms of transport, and particularly bicycle, would have increased in usage. It was noted at the same time - and in fact is confirmed by the 1995 analogue - that there might be more bicycle-related accidents as a consequence. This risk is clearly one that could increase in London if there were better weather. However, it is likely that there would be an adjustment in the behaviour of both cyclists and motorists over time, which would reduce the risk (i.e. as drivers became more used to a higher volume of cyclists on the roads, and as cyclists became more knowledgeable and experienced about the cycling conditions). Much would depend upon safe design of cycling routes and lanes. More cycling to work would create a higher demand for showers at work, requiring installation into new buildings at least, and increasing the water demand of offices.

Stern and Zehavi (1989) conducted research on a road affected by high temperatures (above 24°C) and found that the risk of accidents increased during hotter weather. The research had been carried out on a desert highway, however, which did not have obstacles such as parked vehicles and trees, and found that most accidents consisted of cars running off the road or turning over - a result of heat stress on driver concentration. Thornes (1997) (after Maycock 1995) reports that a survey found that 9% of drivers felt that warm weather induced drowsiness whilst driving. Hotter weather would not only make the experience of driving a car or other vehicle in London less pleasant: it might therefore also increase the risk of accidents. At the same time, the impacts of higher external temperatures would be overcome by the use of AC within cars. This is an increasingly common feature of new cars, and could be expected to become a routine accessory in the next decade or so (at least under GM), even though it reduces fuel efficiency.

A further issue raised by stakeholders as a possibility is that in the event that public transport improvements do not keep track with climate change (air-conditioning was given as an example) this might force people to use private cars more often.

It is also suggested[2] that a significant effect of higher winter temperatures, and in particular lower incidence of frost and snow, would be to reduce the level of resources committed to road maintenance during the winter. This would result in a saving in local authority road maintenance budgets for activities such as salting/gritting that prevent ice forming on road surfaces.

Impacts Due to Wind Storms
High winds, though highly uncertain in the UKCIP02 scenarios, are always a problem for surface transport because of more debris and vegetation which finds its way onto rail lines and roads, causing obstruction and delays. It may be assumed that poorer weather would increase the number of accidents on the roads. At the national scale, that is not the case: the vast majority of road accidents occur in fine weather (Edwards 1999). Thornes (1997) points out that in 1995 two thirds of road accidents occurred on dry road surfaces. One hypothesis of why there are more accidents in better weather conditions is that drivers are much more careful in their driving habits when there are poor weather conditions: there is some evidence of a reduction in accidents in poor driving conditions.

7.3.7 Air Transport

Context
London supports four international airports and three national airports and whilst not all of these airports are within the Greater London area, their workings help to determine the economic functioning of the city, and are determined by the city's economy. London Heathrow is believed to have the highest volume of air traffic of any airport in the world - at approximately 700,000 transport movements per year. With 80 million passengers and an expanding freight burden London Heathrow has a significant role in the local and national economies. Over 120,000 people are currently directly employed in London airports and air transport logistics.

Stakeholder consultation revealed the following potential impacts of climate change on the air transport sector.

Flooding and Rainfall Intensity Impacts
One impact follows directly from the discussion of water freight transport to London, in the sub-section immediately above. If low flows in summer months on the River Thames make navigation by freight carriers more perilous it is likely that there will be some substitution, (though as yet un-quantified), between river and air freight transport modes, with a clear increase in air transport demand and possible positive knock-on effects on road and rail freight links within London.

Temperature Change Impacts
A reduction in winter snowfall and frost frequency will result in reduced time disruption costs as flights are less disrupted, and a reduction in associated cold weather aircraft and runway infrastructure costs.

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[2] J.Palutikof Pers. comm.

It was suggested in the stakeholder consultation that there may be substitution between tourist destination in the event of an increased incidence of hot summers. Domestic holidays may be taken instead of international holidays, with an associated fall in demand for international flights. In the case of the 1995 analogue it was estimated that an extra £1.2 million were spent on domestic flights, whilst £12 million less were spent on international tourist flights. The remainder of the increase in domestic travel was met primarily by car and train modes of transport. The issue of tourist travel patterns is discussed in more detail in the Tourism section below.

Impacts Due to Wind Storms

There may be more disruption from storm events (with high winds and lightning frequency) in winter months.

7.3.8 Historical Analogue of Climate Change Event

The analysis above has made reference to the 1995 analogue of a hot summer. The report by Palutikof et. al. (1997) on the economic consequences of this summer (and unusually warm year more generally) provides a quantitative summary of the costs and benefits involved for the UK as a whole and this is reproduced below in 2002 prices. It is recognised that these results should be scaled down according to the proportion of the costs and benefits the transport infrastructure of London contributes to the UK total, though we have no reliable way of doing this. In any case, the values are no more than indicative of the type and scale of costs/benefits that would be involved in the future.

Table 7.2 Estimated costs and benefits of the weather of 1995 on air, rail, road and water transport (£ million)

Transport Mode	Benefits	Costs
Air Transport	Increased internal holiday flights (£1.16m)	Loss of overseas holidays (£11.6 m)
Rail Transport	Increased revenue from holiday and leisure trips (£11.6 m)	Rail buckles (£1.16m)
		Speed restrictions (£1.16m)
		Lineside fires (£1.16m)
Road transport	Reduced maintenance costs (£9.4 m)	Increase in pedal cycle accidents (£14m)
		Road rutting repairs etc (£11.6 m)
Water transport	Reduced delays to offshore shipping (£1.16m)	Closure of canals - loss of income (£1.16m)
Totals	Benefits £23.32m	Costs £41.84m

7.3.9 Socio-Economic Scenario Differences

It is difficult to say whether pressure of use on the underground, trains and buses would be greater under GM or RS. Under GM, there would be more people in the capital, but under RS there would be a move towards more public transport, both of which result in higher underground use. Under GM, the response to unpleasant travelling conditions on the underground and trains might well be greater use of private cars, increasing congestion on the roads and, presumably, encouraging more private-sector investment in public transport, so acting as a negative feedback (i.e. improving public transport). Under RS, the response might be greater use of walking and cycling. In an RS world, people might live nearer to where they worked so facilitating such solutions. At the same time, under RS, many people might not be able to afford to commute long distances due to general reduction in wealth. Any impacts upon aviation would be more keenly felt under GM than RS, because of the greater international mobility experienced in GM.

It is also difficult to distinguish between GM and RS with respect to the pressure on the transport system heading out of the capital. It would be greater under GM due to more affluent and mobile inhabitants wishing to go on more day-trips or short-breaks around the UK and beyond. On the other hand, under RS there would be more use of local places for holidays, reducing pressure upon airports but potentially increasing demand for travel to traditional holiday destinations around the UK. Under GM, however, we would envisage more car-based pressure, and under RS, more public transport-based pressures. Under GM, air conditioning in cars would be standard, whereas under RS it would be discouraged by government because of the energy penalty. Also, the higher price of fuel under RS would act as a deterrent to automatically include AC in a car purchase. This might mean that car drivers under RS are *more* irritable because of hot weather than car drivers in GM, exacerbated as they are under RS by the poor state of the roads due to lack of investment. On the other hand, under GM there would be more cars and lorries to start with, so that the aggravation of higher congestion levels would be greater than under RS.

7.3.10 Comparison with Other Cities

As noted above, cities with more recently constructed underground systems (Singapore, Hong Kong) have the benefit of being able to include air conditioning, though not without problems. Congestion from cars is a common problem in cities in the industrialised world, though some have tackled it more aggressively through restricting entrance and high zonal charging (e.g. Singapore & Hong Kong). Cities which can use waterways as main transport routes have a slight advantage in that the travel conditions would be more attractive. London might even have a slight edge here over other cities such as New York and Tokyo which, whilst located on the coast, do not have the same accessibility to the inner city areas from rivers running through the urban mass. By contrast, many commercial, cultural, retail and tourist destinations are quite accessible from the River Thames. The transport infrastructure in New York (with its large bridges, docks, harbours, etc.) also seems to be at a greater threat from sea-level rise and extreme events than in London. The large number of tunnels and railway lines located on low-lying coastal strips makes NYC's transport infrastructure very vulnerable to sea-level rise and coastal inundation (Rosenzweig & Solecki 2001). Indeed, one of the structures of a new tunnel bringing water to the New York City (Third Water Tunnel) was raised in response to climate change.

Table 7.3 Summary Table of Impacts - Transport

Climate Change Variable	Associated Impacts	Potential Severity Ranking	Employment Effects	IPPC uncertainty rating	Current availability of adaption options
Increase - winter rainfall	Flooding - time loss, damage repair	H	L - ve	H	Y
Decrease - summer rainfall	Low river flows - freight, tourist disruption	L	L -ve	H	Y
Higher winter temperatures	Less snow - less infrastructure damage	L	L-ve	H	-
Higher summer temperatures	Heat stress - damage repair Greater transport use - leisure Lower transport use - work	L L M	L +ve L +ve L +ve	H H H	Y - -
Increased severity - wind storms	Infrastructure damage, time loss	H	L -ve	H	Y
Sensitivity to socio-economic scenarios		Impacts exacerbated under GM scenario			
Key non climate change sectoral drivers of change		Transport pricing regimes, economic development/planning priorities			
Key stakeholders in impact and adaption analysis		GOL, LDA, TFL, LUL, Port of London Authority, BAA, Local Authorities User Associations			

7.4 Energy

7.4.1 Context

The Mayor's draft Energy Strategy shows that energy consumption in Greater London currently stands at 154 TWh, close to 30% of the UK total. Gas is the most important fuel in London, accounting for 56% of total energy consumption, followed by electricity with 22%. Domestic use accounts for 44% of total energy use, followed by the service sector with 29% and industrial use, with 7%. Some 40% of electricity is generated by power stations located inside the capital. The cross-sectoral importance of energy is underlined by the Mayor's draft Energy Strategy document which states that "Energy supply and use underpin most of the Mayor's eight statutory Strategies - in particular Economic Development, Spatial Development, Transport, Air Quality, Municipal Waste Management and Noise".

7.4.2 Flooding and Rainfall Intensity Impacts

Changes in rainfall patterns with wetter winters and drier summers will have a detrimental effect on the foundations of electricity pylons. In addition, increased wind speeds and increased gust return periods will increase the stresses and fatiguing on power lines, pylons and related assets.

Stakeholders have also suggested that less rainfall in the summer and the associated reduction in cloud cover will provide an opportunity for the solar energy market to expand, both in London and on a national basis.

Clay shrinkage may also impact negatively on the robustness and effectiveness of these networks. An increase in lightning events may also increase the risk of disruption to energy supply as a consequence of damage to the infrastructure.

In the case of hydro-power, which is being mooted as a possibility in conjunction with Thames Water, wetter winters and drier summers will concentrate production even more during the winter months than at present.

7.4.3 Temperature Change Impacts

The most prominent potential climate change impacts on the energy sector are the changes in energy demand that are thought likely to result from higher mean winter and summer temperatures, namely:

- A reduction in the demand for space heating, primarily in spring and autumn; and,
- An increase in the demand for air cooling, primarily in the summer.

Information from a key stakeholder (National Grid) states that evidence has shown, (Palutikof, et. al. 1997), that electricity consumption is beginning to increase during the summer months, almost certainly due to the increased use of air-conditioning and refrigeration. The hot summer of 1995 Quarter 3, (Q3), showed an increase of 2.1% over the temperature corrected consumption. The 1995 Q3 temperature is about 2^0C above the 1961-1990 Q3 average so an increase of 5^0C suggests a summer increase in electricity consumption in excess of 5%, using established non-linear relationships. As the use of air-conditioning in the UK increases from climate and non-climate factors this can assumed to be a lower limit.

In fact it is estimated that more air conditioning (AC) will increase the demand for summer energy, perhaps by 10 to 15% by 2050s, and by 20 to 25% by the 2080s. Warmer winters will generally reduce electricity demand. Energy for heating in the winter is usually provided by gas, whilst AC runs off electricity. Hence, the provision of summer cooling is more expensive than winter warming. Detailed work is required to assess what the change in energy demand in London would be as a consequence of climate change, and hence what is the balance between the increased use of electricity in the summer and decreased gas use in the winter. The increased demand for electricity for AC during 'peak' hours (midday to evening) requires a disproportionately high increase in generation capacity, which would remain idle for much of the time and would therefore incur high capital costs.

This will put further strain on the transmission and distribution networks with a consequent increased risk of 'black-outs' occurring in the system, with associated costs to the economy from disruption of business activities.

To compound the problem, increased average temperature will restrict the load that can be carried by the transmission and distribution networks due to the increased risk of overheating.

It is clear that climate change is likely to exacerbate seasonal differences in demand and perhaps result in a greater degree of associated seasonal demand for contract workers in the energy sector.

7.4.4 Impacts Due to Wind Storms

From the point of view of wind power, increased wind speeds will mean increased production. A 1% increase in wind speed is equivalent to a 3% increase in available wind power. This will be significant for a wind farm off the south-east coast which produces greatest output during the winter months. On the other hand, increases in storm events and more frequent return gusts will increase wind turbine fatiguing.

7.4.5 Communications Infrastructure

The impacts on communications infrastructure as a result of possible climate change in London is considered here since it shares many common features with the discussion of energy infrastructure above. The stakeholder consultation showed that communications are considered vulnerable to a number of climate change related weather patterns including:

Exposure of above-ground infrastructure, e.g. radio masts in the London area, to extreme wind events and a resultant increased risk of service disruption and repair costs. There may also be service disruption to customers in London as a result of damage to infrastructure elsewhere in the UK.

Decrease in summer rainfall resulting in clay shrinkage in many parts of London that may reduce the resistance of below-ground infrastructure, e.g. cabling.

7.4.6 Socio-Economic Scenario Differences

Under GM, one might argue that the costs of climate change would be absorbed by the vibrant state of the economy, and increased energy costs from AC would be readily absorbed. There may, however, be 'thresholds' beyond which comparative costs elsewhere, and perhaps other types of innovation and development to make other cities 'greener' and more pleasant places to live in, would begin to make a difference to the choice of business location (i.e. away from London). These could ultimately suppress the economy, i.e. act as a negative feedback.

7.4.7 Comparison with Other Cities

As for energy demand profiles, climate change will clearly increase the demand for cooling in other cities in Europe, America and Asia. As temperatures and humidity rise, the relative efficiency of AC will decline, meaning that more energy has to be used to achieve successively greater levels of cooling. The Tokyo Electricity Company has estimated that there is a need for an increased electricity capacity of 1,600 MW for each 1°C rise in summer air temperature to cope with the peak demand. This is equivalent to a large power station. The costs of cooling to cities which start from a higher extreme temperature and humidity baseline will be larger, therefore. On the other hand, many of the commercial buildings in London, and most of the domestic buildings, will not already have in place the physical infrastructure of AC units. The capital costs will therefore be greater, though there will possibly be benefits achieved through installation of more efficient modern AC units. The possibilities for more sustainably-sourced energy for air conditioning or cooling have been discussed above (fuel cells, borehole cooling, district CHP, etc.).

7.4.8 A Case-Study of New York City

Peak summer electricity loads already far exceed winter peaks in New York City, because of air conditioning, and the higher temperatures under future climate change will exacerbate this difference, putting further stress upon the electricity system during summer heat waves (Hill & Goldberg, 2001). In the summer of 1999, four successive heat waves hit NYC, the temperature rising to more than 90°F (32°C) for 27 days (and to more than 100°F (38°C) for two days). The peak electricity demand occurred on the 6^{th} July. Brown outs (when electrical power is partially reduced, causing lights to dim) and an extended blackout occurred in the primarily minority neighbourhoods of upper Manhattan and South Bronx (ibid.). Loss of electrical power has serious social, political, economic and health impacts. For instance, the more vulnerable such as the young and elderly are less able to deal with heat stress, and those in high-crime neighbourhoods face increased risk of crime during power cuts. Residents and local politicians in the areas most affected argued that the electricity supplier had not properly maintained the equipment, putting the resident populations at risk. An energy forecasting model has projected that the daily peak load increases in NYC will range from 7 to 12% in the 2020s, 8 to 15% in the 2050s and 11 to 17% in the 2080s (Hill & Goldberg, 2001) (relative to July 1999). (Further research with an appropriate energy model would be necessary to state what the effects of climate change upon load increases in London would be).

Table 7.4 Summary table of impacts - Energy

Climate Change Variable	Associated Impacts	Potential Severity Ranking	Employment Effects	IPPC uncertainty rating	Current availability of adaption options
High winter temperatures	Lower space heating - demand fall	M	L -ve	H	
Higher summer temperatures	Greater air conditions - demand rise	M	L +ve	H	
	Risk of network overheating	M	L -ve	-	
Increased severity - wind storms	Damage to wind power turbines	L	L?	-	
Sensitivity to socio-economic scenarios		Impacts exacerbated under GM scenario			
Key non climate change sectoral drivers of change		Energy pricing - climate change mitigation; regulatory structure			
Key stakeholders in impact and adaption analysis		Regional electricity companies; National Grid; National Power			

7.5 Insurance

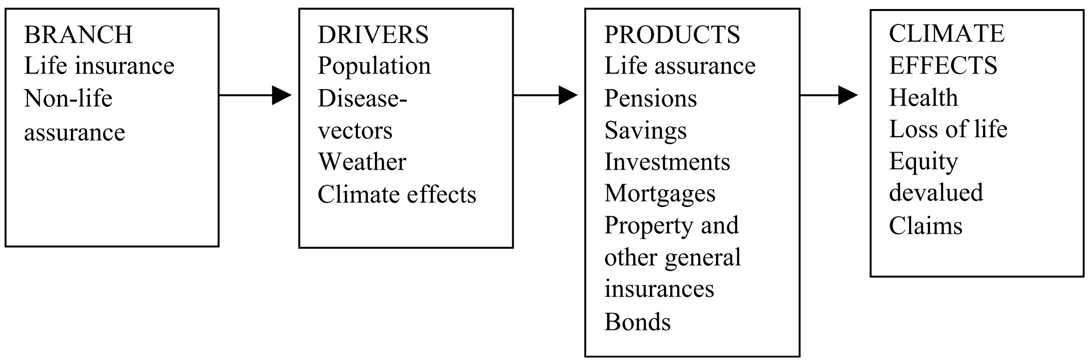
7.5.1 Context

The London based insurance industry comprises approximately 90% of the total UK employment in the industry, (about 300,000), contributing 1.4% of UK GDP. The UK Insurance market is the third-largest in the world and contributes around £8 billion a year to UK overseas earnings, reflecting a broad exposure in global economic activities. The London Market's Gross Premium Income was £17.734 billion in 2000. Insurance companies are the largest domestic owners of UK shares - owning 21% of UK ordinary shares. This compares with 18% held by company pension funds, 2% by unit trusts, and just over 1% by banks. The UK insurance industry in 2000 held £796.5 billion worth of assets globally.

The UKCIP Scoping Study for the South East of England describes in general terms how the UK based insurance industry is likely to be impacted by climate change in the UK. The study notes that since "many activities within the insurance sector are weather sensitive, the industry has developed wide experience and understanding of how weather conditions impact on its operations. These include claims associated with severe short term events including rain and windstorms, freezing weather and longer term events such as hot, dry spells the latter increasing building susceptibility to subsidence".

Dlugolecki, in Chartered Institute of Insurers (CII) (2001) generalises the interaction between insurance and climate change as illustrated in Figure 7.1 below.

Figure 7.1 Life and non-life insurance activities and climate change



The diagram shows that the core activities of insurance companies are likely to be impacted by climate change either by changes in risk transfer arrangements, changing vulnerabilities of financial and non-financial assets held, and wider economic changes. The different types of climate change impacts most likely to be important to the London insurance market are discussed in more detail below.

7.5.2 Flooding and Rainfall Intensity Impacts

As noted elsewhere in this report, London is exposed to far greater potential damage from flooding than any other urban area in the UK. This is due to the scale of the city and the fact that a significant proportion of London lies within the floodplain of the River Thames and its tributaries.

The UK is unusual in that flood insurance is currently offered as standard with buildings and contents policies. Property damage as a result of river, and other sources of, flooding is covered to some degree for almost all insured properties in the UK. Thus, the higher rainfall incidence predicted for the UK by the London and UKCIP02 climate scenarios is likely to result in an increased value of claims against the insurance industry. A recent analogue of this type of event were the floods of Autumn 2000. In this case, 12,000 properties were damaged and a further 37,000 properties were classed as 'near misses' by the Environment Agency. The total cost for the UK insurance industry to date is over £1.0 billion.

The causes of flood risk are not confined to tidal or river flooding. Other particular concerns for London include:

- The large size of urban catchments;
- The rate of development of new housing and associated development in the main drainage tributary systems;
- Particular hazard of short duration, intense storms on the drainage systems (foul and storm);
- The ageing condition and lack of capacity of existing drainage systems;
- Impact of rising groundwater in conjunction with surface flooding.

Even new drainage systems are designed to cope only with normal rainfall levels. Recent research has shown that climate change will mean that many of these systems will surcharge several times a year in the future (Futter and Lang, 2001). Stakeholders hope that the threat of this flood risk will be reduced by the Sustainable Urban Drainage Systems (SUDS) initiative promoted by the Environment Agency and the Scottish Environment Protection Agency which aims to promote good practice in the construction of robust drainage systems with sufficient capacity to cope with rainfall events foreseen by the London climate change scenarios.

Exposure to River Flood Risk and Adaptation Strategies
A number of adaptation options for reducing flood risks likely to arise from climate change in London are outlined in Section 5 and the section on water resources in this section, above. In the following paragraphs an insurance industry perspective on the current development of flood prevention strategies is presented.

7.5.3 Temperature Change Impacts

Palutikof (nbu.ac.uk web-site) points out that freezing weather causes damage even in a relatively mild winter, when a short episode of very cold temperatures can cause substantial claims for burst-pipe damage. Also householders are more likely to take a winter holiday, leaving the house empty and unheated. The balance of opinion in the industry suggests that these two factors more or less cancel in the present climate. Potential claims from this type of weather event are significant for the industry (though less than flood and storm costs): it is estimated that £250 million of claims resulted from such an event in 1996 in the UK. This type of effect may be expected to reduce in frequency as a result of the warmer winters expected under the climate change scenarios for London.

According to the Association of British Insurers, their members already incur costs of nearly £1m every day on average from subsidence. This is likely to be a growing issue as summers become drier and warmer, causing soils to shrink. Subsidence should not be a major hazard - the fact that it is so costly in Britain, especially England, is more to do with issues around building foundations and building standards. A new technique using satellite data, called Permanent Scatterer Synthetic Aperture Radar Interferometry (PS InSAR) is making it possible to measure sub millimetre movements in buildings. This could identify the worst subsidence areas. It could also give early warning of failure of mass structures such as bridges, flood defences, power stations and dams.

7.5.4 Impacts Due to Wind Storms

It is becoming clear, whether or not storms will become more frequent and severe with climate change, that storm tracks are changing. In the past, it was normal for stable cold high pressure areas to develop over Switzerland and Germany in the winter. These 'blocking highs' diverted Atlantic storm tracks over the North of Scotland or Spain where houses have been designed to cope with them. As winters in central Europe become milder, the blocking highs are becoming weaker or shifting to the East (Parry et al., 2000). When there are milder winters in central Europe, more storms track across the South of England and the North of France (Dronia, 1991) where buildings are designed and constructed to lower standards. Existing historical analogues show that there are high costs for the insurance industry of these type of events. The October 1987 storm cost insurers £1,500m at 1987 prices for UK damage alone. Overall, including continental European losses, the economic loss was \$3,700m of which the insured loss was \$3,100m. Two further such storms in England in January and February 1990 ('Daria' and 'Vivian') caused insured losses in England of £2,400m (at 1990 prices). The overall European economic losses were \$10,050m of which insured losses (at 1990 prices) were \$7,200m. Three big storms in December 1999 ('Anatol', 'Lothar', and 'Martin') did not affect England seriously, but devastated large areas of Northern and Western Europe, causing economic losses of \$12,700 m of which insured losses were \$6,200 million (Munich Re, 2002).

Future extreme wind storm events are expected to be one of the most significant of the climate change impacts for the insurance industry because of the associated claims for business disruption, utility and transport infrastructure damage and domestic property damage.

An insurance stakeholder view is that there is a clear lesson here for adaptation strategies. Storms in London are likely to become more severe and frequent, but as buildings in London have been designed for relatively benign weather conditions, they are likely to be more vulnerable to storm damage. This needs to be taken into account when revising the Building Regulations. It will also be necessary to have more stringent control through inspections on the quality of construction and the resilience of buildings to storms or floods.

7.5.5 Raised Reservoirs

A study was carried out of the climate change impacts on the safety of British Reservoirs, using the UKCIP98 climate scenarios. The study concluded that under a medium-high climate change scenario the total surcharge (i.e. rise in water level above normal retention level during a storm) could increase by about 5% by the 2050s and that embankment dams might be more vulnerable than concrete and masonry dams. The report also strongly recommended that climate change should be taken into account in future reviews under the Reservoirs Act 1975. (Babtie and Institute of Hydrology, 2002). It should however be noted that reservoirs in the London area do not impound rivers but are filled by pumping water into them from rivers under a managed operational regime.

More than 50% of Britain's reservoirs are over 100 years old and made of earth embankments. The Reservoir Act 1975 stipulates a regular inspection program for all reservoirs which ensures that structural integrity is maintained.

There are several raised storage reservoirs in the Greater London area for example along the Thames and Lee valleys. These are often situated along rivers but may also be near urban areas. Although the risk of failure is low, planners need to be aware of the potential hazard when considering new housing developments in such areas. Future climate change impacts are considered as part of the mandatory maintenance and inspection program of all dams and any new development built near to the reservoirs have the same level of protection as existing properties under the class A rating of the dams, this is a statutory provision under the Reservoir Act 1975.

7.5.6 Potential Meso- and Macro-economic Effects of Climate-Change Related Impacts on the Insurance Industry

The current practice is for insurers to offset underwriting losses - of the type identified above as resulting from climate related events - against investment income. A consequence of this is that investment returns are likely to fall, with a subsequent re-alignment of premium payments - and therefore consumer prices - upwards. A related consequence if the climate event is severe enough - as it was for the 1987 windstorm - is that insurance companies may be forced to reduce their level of capitalisation in capital market or property market equity. In this instance, there will be a downward shift in equity prices which reduces liquidity in the financial sector and has a deflating effect on investment in the economy, and therefore economic growth. Such a reduction in the level of capitalisation of the industry is also likely to be accompanied by internal retrenchment of insurance operations and a shrinkage in employment levels in the sector.

The threat to the sector identified above in the UK is exacerbated significantly by the high level of inter-dependence that exists in global capital and insurance markets. The scale of climate change impacts identified for the UK may potentially be significantly increased by climate change in other parts of the world, where assets are insured against damage in the London insurance market. For example, where an incidence of increased tropical storms is expected (as in the southern states of USA and the Caribbean), buildings and transport infrastructure are likely to suffer increased levels of damage - assuming existing construction specifications - leading to increased claims against the insurance industry. Indeed, such claims will impact on the London-based insurance and financial services industries even if the insurer claimed against is not based in London since there might be a (marginal) global squeeze on financial liquidity. These types of future risk changes are already being considered in the development of the global market strategies within the London insurance industry.

IPCC (2001) notes as a measure of insurance vulnerability the ratio of global property/casualty insurance premiums to weather-related losses fell by a factor of three between 1985 and 1999. The IPCC synthesis concludes that 'there is high confidence that climate change and anticipated changes in weather-related events that are perceived to be linked to climate change would increase actuarial uncertainty in risk assessment and thus in the functioning of insurance markets'. As one insurance sector representative commented in the course of the project consultation, "insurance has historically been about predicting the unpredictable. Climate change means that predicting the unpredictable itself becomes unpredictable."

To avoid this level of exposure to loss, the UK insurance industry is engaged with the sectors - such as property, transport and regulatory authorities - to develop effective and equitable adaptation strategies. Some specific adaptation options are highlighted above and CII (2001) gives further detail on these.

7.5.7 Socio-Economic Scenario Differences

Under the GM scenario there will be an expansion of the global insurance market as regional markets are increasingly linked with each other. This will be reflected in a greater degree of trading opportunity for economic assets of all sorts and a consequent increase in the need to insure them. This effect is more significant at the global scale rather than the national scale since in the UK property already has a high degree of insurance coverage. Under this scenario, therefore, the insurance industry may be more exposed as climate change reduces the robustness of existing actuarial calculations relating to the rates of premiums that are based on non-climate change weather patterns. The RS scenario is likely to feature a consolidation of the global insurance industry - increasingly based around regional commercial centres.

7.5.8 Case Study

Since 1961, private insurers in Britain have had a form of partnership with government in that they offer flood insurance for every household at a reasonable price. This arrangement is unique to Britain. The insurance industry has recently reviewed its position because:

- In the United Kingdom, the government regulator for insurance is the Financial Services Authority (FSA). In 2001, the FSA issued risk-based criteria for assessing the solvency of insurers. One of the effects of this is that if an insurance company takes on too much business in areas at risk of flood, it could be subject to FSA audit. This may be unlikely in the short term, but it is a possibility that directors of insurance companies must take into account, and they will need to ensure that accumulations of flood hazard exposures are properly managed.
- In recent years there have been an increasing number of new housing developments in floodplains to the extent that there are now large accumulations of exposure in flood hazard areas especially in London. The reasons include increased demand for housing in such areas where suitable sites are limited, together with the continuing availability of insurance that has enabled people to borrow money to buy the houses.

In addition the widespread flooding in Autumn 2000 in various UK locations led insurers to review the sustainability of flood cover in high-risk areas. Insurers (through the Association of British Insurers) responded to concerns over the continued availability of flood cover by committing to a two-year agreement for existing domestic properties and small business policyholders. At the time of writing this agreement expires at the end of 2002. In return the insurance industry is seeking a greater investment by the government in prioritised flood defence expenditure and a tightening of planning control on development in the floodplain through the implementation of Planning Policy Guidance Note 25 ‘Development and Flood Risk’.

Table 7.5 Summary table of impacts - Insurance

Climate Change Variable	Associated Impacts	Potential Severity Ranking	Employment Effects	IPPC uncertainty rating	Current availability of adaption options
Increase - winter rainfall	Flooding - insured damage to property	H	H -ve	H	Y
Decrease - summer rainfall	Subsidence to insured property	M	L?	H	Y
	Damage to dams - break over property	M	L?		
Increased severity - wind storms	Infrastructure damage - insured	H	H -ve	H	Y
Sensitivity to socio-economic scenarios		Impacts significantly exacerbated under GM scenario			
Key non climate change sectorial drivers of change		Economic growth; development of global insurance markets			
Key stakeholders in impact and adaption analysis		CII, ABI, UK Govt., Banks, Construction companies			

7.6 Financial Services

7.6.1 Context

The financial services sector is the largest employer in London (32% of total), and excluding the insurance industry, employs about 700,000. Professional and support services such as legal services, accounting and management consulting employ a further 600,000 people. The draft London Plan envisages the protection and enhancement of this sector as a principal mechanism by which London's economic development can be driven, and by which London's status as a global city can be maintained.

7.6.2 Flooding and Rainfall Intensity Impacts

Much of the discussion on climate event risk changes and their repercussions for the insurance sector are relevant to the wider financial service sector in London because of the inter-linking of insurance and capital markets. Figure 7.2 below illustrates the extent of these linkages.

As an example of the linking mechanisms, the case of lending can be cited (IPCC, 2001). Most private and corporate loans are secured by property. If a region such as London becomes more exposed to climate-related natural disasters such as floods or windstorms, the prices for property could fall - which may result in a loss of confidence in the local economy and may trigger a credit crunch of the sort described in the section on insurance. An indirect consequence of this is that other types of business such as management of private assets and granting of private loans that are not backed by property will also be affected (Bender, 1991; Thompson, 1996).

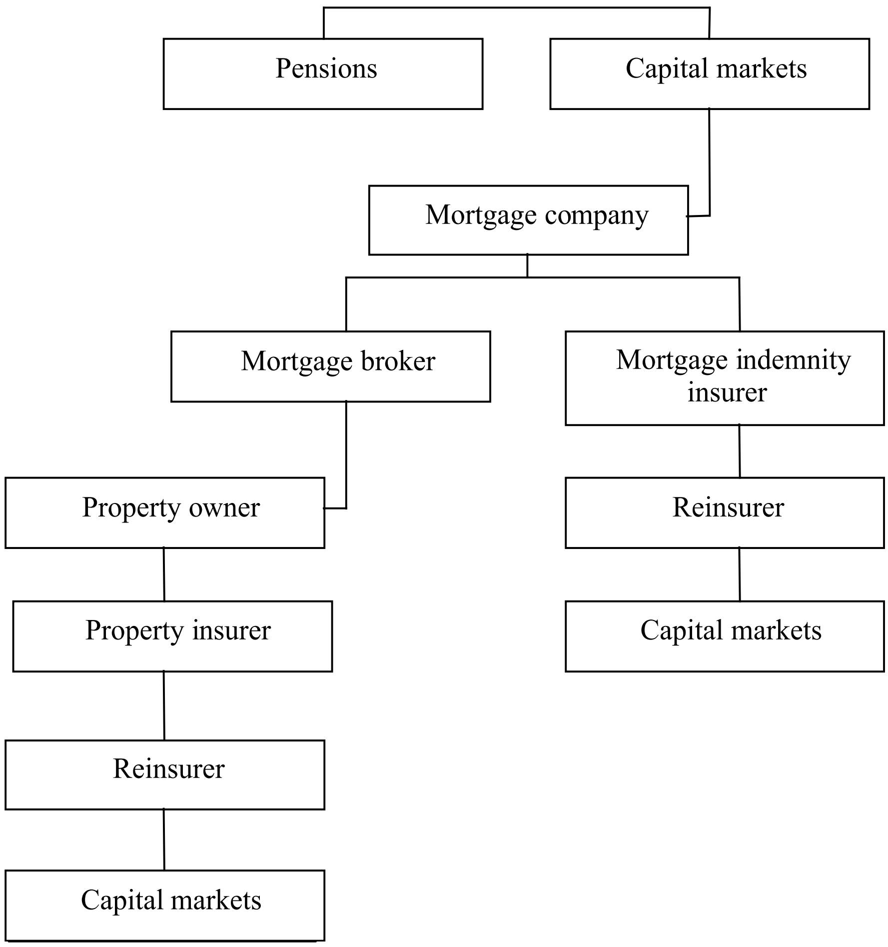
7.6.3 General Climate Change Impacts

There are divergent views on how the banking sector will be impacted by climate change. One view is that the nature of the industry - large, diversified banking institutions - means that any loan exposure will be minimal since no substantial portion of the loan will be kept for any long period. Alternatively, should their customers operations or financial circumstances change as a result of climate change, (e.g. international tourism), the banks performance could be affected indirectly.

The stakeholder consultation did, however, identify a strong feeling that the risk management of potential climate change impacts, coupled with the implementation of regulatory regimes for greenhouse gas emission mitigation, provide significant business opportunities. Risk management is resulting in the development of markets for e.g. catastrophe bonds and weather - related trading in the international financial markets.

Similarly, the reality of a carbon-constrained future for all business is already manifesting itself in the application of energy-focussed audit work for consultancies as energy use becomes a part of companies' business strategy. There is likely to be a major verification role as Kyoto Protocol regulatory mechanisms such as Joint Implementation and Clean Development Mechanism are enforced. Finally, there is a developing market in carbon trading which London is in a very good position to exploit as an established trading centre. It was noted by one stakeholder, however, that Chicago currently lead the way in this market, benefiting from the fact that the US are likely to be the major buyers of carbon credits in future! All these opportunities for mitigation are likely to be enhanced as the recognition of potential climate change impacts, e.g. flood risk to London, that should be avoided stir a greater regulatory response from national governments.

Figure 7.2 Insurance - Capital Market Linkages



7.6.4 Socio-Economic Scenario Differences

As with the insurance sector, the financial services industry in London will have significant opportunities to expand in the GM scenario. The rapid rate of expansion in IT technologies and communications on a global basis would allow increased opportunities for participation in the trading of climate change mitigation and weather risk financial instruments. Under the RS scenario, there may be a further development of e.g. EU permit trading regimes but the level of growth will be less than under the GM scenario.

Table 7.6 Summary table of impacts - Financial

Climate Change Variable	Associated Impacts	Potential Severity Ranking	Employment Effects	IPPC uncertainty rating	Current availability of adaption options
Increase - winter rainfall	Flooding - property damage - equity market falls	H	M -ve	H	N
Increased severity - wind storms	Infrastructure damage - equity market falls	H	M -ve	H	N
Existence of climate change impacts	Devt. of new weather risk management tools	M	L	H	-
	GHG mitigation regulation	M	L	H	-
Sensitivity to socio-economic scenarios		Impacts significantly exacerbated under GM scenario			
Key non climate change sectorial drivers of change		Economic growth; merger strategies			
Key stakeholders in impact and adaption analysis		Corporation of London, UK Govt, Banks, Consultancies			

7.7 Manufacturing

7.7.1 Context

Whilst the sector has suffered a long term relative decline, manufacturing in London is presently responsible for 300,000 jobs and £10 billion of output. It comprises 10% of all UK manufacturing. London's largest manufacturing industries are: food and drink, advanced automotive, aerospace and precision engineering, as well as high-tech industries such as pharmaceuticals, fibre-optics and computing. It is these industries which the draft London Plan envisages consolidating and expanding to 2015.

In general terms, manufacturing businesses are most likely to be impacted upon by climate change in the following ways, where the industry is dependent on climate-sensitive natural resources, and their supply is affected:

- Through consumer behaviour that is sensitive to climate variability;
- Through transport disruption that affects just-in-time industrial processes.

7.7.2 Flooding and Rainfall Intensity Impacts

The economic costs of transport disruption were identified in the section above on transport. The stakeholder feeling is that disruption to road and train modes from flood and storm damage are likely to be the most costly for industry.

There was a stakeholder recognition that changes in water resource availability and/or prices in the London region - highlighted above - may have impacts on certain industries in the city that use large amounts of water in their manufacturing processes. The most likely impacted industries are thought to be the drink sector (and particularly brewers) and the automotive industry, though no work is known to have been undertaken on this issue.

7.7.3 Temperature Change Impacts

The effect of climate-induced changes in consumer behaviour are generally related to temperature changes. The study by Palutikof et. al. (1997) of the 1995 hot summer provides an analogue of how such conditions may impact on retailing and manufacturing in the future. They found that there was a net cost to the retail market in total of £102 million (2002 prices), whilst the loss for the clothing and footwear market was estimated at £410 million for the UK as a whole. There was a small gain of £27 million in the fruit and vegetable markets. Clearly, these types of effects have parallel knock-on impacts on the associated manufacturing sector.

A general point common to all the sectors included in this analysis - but perhaps particularly relevant to the manufacturing sector - is that warmer weather in summer will result in more uncomfortable working (and travel) conditions. This may have an effect on productivity, and an adaptation strategy will need to weigh up these productivity costs against e.g. building ventilation. As mentioned elsewhere, there may also be sectoral and geographical relocation resulting from this climate change impact.

7.7.4 Impacts Due to Global Climate Change

The dependency on climate-sensitive natural resources, and possible supply disruption is thought by stakeholders to be most relevant to the food and drink industry where there is a heavy reliance on imported food stuffs. However, the range of evidence on changes in food production is very wide, and it has led IPCC (2001) to draw a single conclusion: that, with very low confidence in its robustness, a global temperature rise of greater than 2.5°C is likely to exceed the capacity of the global food production system to adapt without price increases. However, results are judged to be too mixed to support a defensible conclusion regarding the vulnerability of the global balance of agricultural supply and demand to smaller amounts of warming than 2.5°C.

7.7.5 Socio-Economic Scenario Differences

Under the GM scenario, traditional manufacturing continues to decline whilst high-tech manufacturing increases. It is possible, therefore, that the threat to the traditional part of the sector from supply disruption caused by climate change events elsewhere in the world will be reduced in the GM scenario but increased under the RS scenario.

Table 7.7 Summary table of impacts - Manufacturing

Climate Change Variable	Associated Impacts	Potential Severity Ranking	Employment Effects	IPPC uncertainty rating	Current availability of adaption options
Global climate change impacts	Prince increases in e.g. food stuffs	M	M -ve	L	Y
Increase - winter rainfall Decrease - summer rainfall	Likely net deficit in supply - dem and balance - price rise	M	L - ve	H	Y
Higher winter temperatures	Changes in consumer behaviour	L	L?	H	-
Higher summer temperatures	Changes in consumer behaviour	L	L?	H	-
Storm frequency/severity	Distribution disruption	M-H	M -ve	H	Y
Sensitivity to socio-economic scenarios		Impacts possibly mitigated under GM scenario			
Key non climate change sectorial drivers of change		Economic growth; international market competition			
Key stakeholders in impact and adaption analysis		Corporation of London, UK Govt, FSB, CBI, Unions			

7.8 Environmental Business

7.8.1 Context

Environmental business is most commonly associated with the recycling of materials though the definition should be broad enough to cover any business activity that is responsive to environmental issues and problems. Thus, the substantial business that has arisen in the regulation of environmental impacts (e.g. environmental impact assessment, greenhouse gas emission trading etc) may be considered under this heading. This activity is discussed in the Financial Services section. Other environmental businesses include those related to energy efficiency, flood protection engineering, waste management, consultancies etc. According to the draft London Plan, the size of the sector in London is now equivalent to the pharmaceutical sector, and forecast to double by 2010.

7.8.2 Impacts Due to Global Climate Change

The most significant climate change impact thought likely to affect the recycling industry in London is the possible increased demand for recycled materials in manufacturing and retail sectors as a result of relative price changes between recycled and virgin raw materials from climate change impacts elsewhere in the world. The argument is that climate change impacts in other parts of the world, such as South Asia, may have an impact on the supply of certain raw materials for manufacturing. If supply is restricted – either by transport disruption or cultivation patterns changing as a result of negative changes in temperature or rainfall – the price of the commodity will rise, other things being equal.

Moreover, assuming a constant price of recycled raw materials, it is likely that there will be some switching of demand from virgin materials to recycled materials, and a consequent expansion of this type of environmental business. This argument may be the case for paper of which a significant part of the market share is presently manufactured from virgin pulp in South and East Asia. Current estimates of cultivation pattern changes (IPCC, 2001) tentatively suggest a 1-5% increase in price for paper pulp in the next 15 years as a direct result of temperature and rainfall changes. Although low confidence is placed in these estimates at present, it is recognised that any change in relative prices of this nature will have a positive effect on UK paper recycling industry. A similar argument can be made for the rubber recycling industry since virgin rubber is also presently supplied from Asia. There is therefore a potential opportunity to be exploited here – though it is clearly a regional, rather than a global, welfare gain.

7.8.3 Impacts Due to General Climate Change

Two closely related arguments suggest that climate change impacts might have a positive effect on environmental businesses.

First, it is possible that with heightened awareness of human responsibility for environmental change, (such as the link being made between greenhouse gas induced climate change and the Autumn 2000 floods in the UK), more pro-active steps will be taken by producers or consumers to ensure that their actions have less of an environmental impact. This might manifest itself either in reduced consumption levels or the use of more recycled materials, (and hence benefits for environmental businesses), or both.

The related argument is that as a result of such increased awareness within the general public and in government, increased regulation of activities that have environmentally detrimental consequences will result, with benefits for environmental businesses more generally. It should be noted, however, that this outcome may simply shift employment from one sector (e.g. the regulated industry) to another (environmental consultancy), with no net gain. A wider perspective on this might suggest, moreover, that it is preferable for producers to be pro-active and look for opportunities with which to exploit an environmental profile to competitive advantage without relying on a legislative driver.

7.8.4 Socio-Economic Scenario Differences

The RS scenario, with its greater awareness of the value of the environment for its own sake, is likely to exacerbate the tendency for environmental business sector to expand as increased awareness of climate change results in increased demand for all kinds of environmental product or service. It is possible also that the GM scenario will result in the expansion of e.g. recycling markets, with an increased consequent scope for exploiting virgin-recycled price differentials.

Table 7.8 Summary table of impacts - Environmental Businesses

Climate Change Variable	Associated Impacts	Potential Severity Ranking	Employment Effects	IPPC uncertainty rating	Current availability of adaption options
Global climate change impacts	Price increases in virgin raw material relative to recycled	M	M +ve	L	-
Existence of climate change impacts	Changes in producer/consumer behaviour	L	M +ve		-
Sensitivity to socio-economic scenarios		Impacts exacerbated under RS scenario			
Key non climate change sectorial drivers of change		Sustainability awareness			
Key stakeholders in impact and adaption analysis		Recycling/environmental businesses; UK Govt.; manufacturers; consumers			

7.9 Tourism and Leisure

7.9.1 Context

Tourists visiting London from elsewhere in the UK account for approximately 10% of total UK domestic tourism (ONS 2001). London is by far the most popular UK destination for overseas tourists, however, accounting for just over half of all overseas tourists and associated expenditure. In 1998, 13.5 million overseas tourists travelled to London. The domestic tourists bring in just over £1 billion, but the overseas tourists contribute nearly £7 billion to the London economy (ONS 2001). Hotels and restaurants comprise 5.8% of London's GDP.

London has an impressive set of facilities and attractions for tourists including the following (LTB at www.englishtourism.org.uk 2002):

- 1200 hotels (269 of which are of historical interest);
- 12,155 restuarants;
- 5,245 pubs and bars;
- 200 museums;
- 108 theatres.

7.9.2 Flooding and Rainfall Intensity Impacts

- Sports and recreational fishing could suffer in dry summers;
- There may be insufficient water to maintain inland canal navigation. This could also effect the attractiveness of canal-side commercial and residential developments;
- Increased likelihood of algal blooms on watercourses with aesthetic and health implications.

7.9.3 Temperature Change Impacts

There is a high degree of uncertainty as to what the net effect of climate change is likely to be on Tourism in London but the principal arguments are:

- Southern Europe and other destinations might become less attractive as a destination for summer holidays since climate change there will result in intolerable hot temperatures. More summer holidays will therefore be taken domestically, with time spent in London being one component of such a holiday.
- A recent study, (Agnew and Viner, 2000), has identified potential impacts of climate change on ten overseas holiday destinations. The threats of these predominantly negative effects (examples of which are shown in Table 7.9 below) will strengthen the argument above.

Table 7.9 Potential impacts of climate change on holiday destinations

Location	Climate Change impacts
Greece & Turkey	Heat stress/mortality; water supply restrictions; forest fires, urban smog
Southern Spain	Re-emergence of malaria; heat stress; flash floods; forest fires
Florida & S.E. coastline of USA	Sea level rises affecting recreation and tourist activities concentrated along the state's beaches; severe storms discouraging holiday makers; erosion and coral bleaching; threat to geomorphology and ecology

To exploit this possible opportunity will require maintaining a high quality environment, efficient transport systems and sufficient capacity to cope with a rise in tourist numbers (visitor management). If climate change also results in increased visitors to the UK as a whole, this would have implications for London, since the city's airports and stations are the gateway to most visitors to the UK. On the other hand, heat waves might deter visitors to London. In the workshop, it was recognised that tourists do still visit Italian and Spanish cities in the summer. London in 50 years would be unlikely to exceed the temperature of popular tourist cities in southern Europe now, so it seems unlikely that the temperature *per se* would be off-putting.

Indeed, if temperatures were to increase significantly in other cities which are currently popular tourist destinations, such as Venice, Florence, Rome, Barcelona, Seville, New York, etc., then it could be argued that they would indeed become less attractive tourist destinations, at least during the summer. In this case, there could be a transferral of visitors to London from those cities, at least during the hotter parts of the year. Many hotels in London do not have air conditioning at present, however. This, or alternative means of cooling rooms, would be necessary to provide a high quality destination. Similarly, cafes, restaurants, visitor attractions and retail centres would also require air cooling systems to remain at a high quality. Increased air pollution related to climate change would likely have an adverse impact upon tourism, as is suggested from the experience of Athens and Los Angeles.

The changing climate may also have an impact upon the availability of some natural recreational resources Rivers, canals and other bodies of water would probably become more attractive destinations, provided that water quality could be maintained sufficiently. The draft London Plan includes the Blue Ribbon strategy which sets out a comprehensive agenda for utilising canals and rivers and other water bodies for leisure, recreation, tourism, redevelopment and commerce (GLA 2002a). As noted above, river-based commuting would be a cool option for some. There would be greater demands placed upon the existing swimming pools, of which there are 144 in Greater London, and outdoor recreation centres, including sites such as the Hampstead Heath Ponds. The Royal Parks would perhaps make their water bodies available for bathing, as they have done on very hot days in the past. This would carry with it health and safety implications, however, since water quality would have to be inspected and potential hazards from Lyme disease, broken glass and underwater objects, etc., would need to be monitored.

Summer heat-waves in London and the heat island effect will encourage London residents to leave the city for short recreational trips. Theme parks and similar out-of-town excursion destinations may benefit. Destinations such as Thorpe Park, Surrey, which specialise in water features may be expected to benefit substantially.

7.9.4 Socio-Economic Scenario Differences

Under GM, global tourism would continue to expand, mainly through aviation bringing individuals from around the globe to far-flung destinations. London would continue to draw in visitors from all over the world. Under RS, on the other hand, there would be much less global tourism. There would probably be less London-based tourism, as the spatial pattern of tourism demand would tend to distribute more evenly around the UK. The international tourism market is, by contrast, strongly concentrated in and around London.

Table 7.10 Summary table of impacts - Tourism and Leisure

Climate Change variable	Associated Impacts	Potential severity ranking	Employment effects	IPPC uncertainty rating	Current availability of adaption options
Global climate change impacts	London more attractive compared to traditional destinations	L	M + ve	L	-
Higher summer temperatures	More trips outside London	L	L?		-
Lower summer rainfall	Water-based recreational occupations threatened				
Sensitivity to socio-economic scenarios		Impacts limited under RS scenario			
Key non climate change sectoral drivers of change		Economic growth			
Key stakeholders in impact and adaptation analysis		LDA; GLA; London Tourist Board			

7.10 Public Administration

7.10.1 Context

It is estimated that 19% (600,000) of the labour force in London are currently employed in public administration. The structure and content of the work of public administration is led by the elected political representatives at local, regional, national and EU level. The sector is therefore important as an employer, and in determining patterns of economic and social development in the city.

London's local authorities have a key role as community leaders and service providers. Many have already started to address climate change issues in their Unitary Development Plans as well in their community and Local Agenda 21 strategies. They have a key statutory role in implementing strategies in a number of areas affected by climate change such as housing, transport and environment. Many local authorities are committed to working with their communities as well as stakeholders including other public sector agencies and business to assess the potential effects of climate change and identify ways in which local authorities can adapt to climate change.

The chief potential impacts identified by public administration stakeholders consulted during this study, including the Government of London, GLA and local authorities etc. were:

- possible consequences for the supply of a well-educated labour force for senior positions;
- the need to incorporate more thoroughly the potential economic and social impacts of climate change in sector development strategies, and their operationalisation.

7.10.2 Impacts Due to General Climate Change

Possible general consequences of climate change on the attractiveness of London as a place to live and work have been described in detail elsewhere in this report. The stakeholders from the public administration sector specifically suggested that the move towards relocation from the city by parts of the public administration workforce may be significant - primarily as a result of the perceived heat island effect. This relocation may be accompanied by a shift to other sectors from those parts of the workforce with more transferable skills, and an increase in tele-working and consequent fall in commuter journeys.

The move towards greater inclusion of potential climate change impacts - and associated adaptation measures - in public policy design was identified by stakeholders as the general increase in awareness of environmental issues.

7.10.3 Socio-Economic Scenario Differences

A greater awareness of environmental values that characterises the RS scenario will exacerbate the impacts identified above for public administration. In particular, this awareness relating to climate change will result in an increased slant towards the content of public administration taking on environmental considerations to a greater degree than at present. An opposite effect might be expected under the GM scenario.

Table 7.11 Summary table of impacts - Public Administration

Climate Change variable	Associated Impacts	Potential severity ranking	Employment effects	IPPC uncertainty rating	Current availability of adaption options
Existence of climate change	Integration of CC impacts and adaption into strategy	M	L?	-	Y
Higher summer temperatures	Relocation - lower skilled labour supply	L	L -ve	M	-
Sensitivity to socio-economic scenarios		Impacts exacerbated under RS scenario			
Key non climate change sectoral drivers of change		Socio-economic development patterns			
Key stakeholders in impact and adaption analysis		GOL, LDA, GLA, UK National Govt, EU			

7.11 Creative Industries

7.11.1 Context

Key creative industries include music, fashion, new media, film and broadcasting. They employ more than 400,000 people in London and generate £20 billion per annum. It is one of the fastest growing sectors of the London economy. The sector - apart from in the broadcast media - is characterised by being made up of small and medium enterprises located in clusters in West London, as well as in areas such as the Lower Lee Valley and Deptford Creekside.

The project stakeholder consultation has identified the following as the most likely impacts of climate change in this sector.

7.11.2 Flooding and Rainfall Intensity Impacts

Further expansion of the industry into the Thames Gateway, as suggested by the draft London Plan may increase the flood risk of the properties that are occupied by the sector unless flood prevention measures are undertaken - as described in the sections above. One range of options is presently being generated by the sector itself - innovative urban design. The Mayor's Architect and Urbanism Unit is understood to be co-ordinating such work as part of the Mayor's 100 Spaces project. The work of this unit, and others involved in this area, is likely to contribute to other areas of building design that can mitigate climate change impacts on buildings and other urban areas, such as temperature and ventilation issues. This area of business can therefore be seen as an opportunity for London in terms of there being a new market arising out of the need for adaptation on a global basis.

7.11.3 Impacts Due to General Climate Change

Climate change impacts on labour supply to London may have a role in determining future growth of the sector. Specifically, any accelerated movement from the city because of a decline in its relative attractiveness against e.g. creative centres in Europe e.g. Paris, or in the US - most notably New York - may undermine such growth.

7.11.4 Socio-Economic Scenario Differences

Under the GM scenario media is likely to consolidate further at the global scale, with a parallel continued expansion in multi-media. If we consider the adaptation of buildings to flood risk and other climate change effects as an opportunity for the design industry globally, then it may be that a consolidation may be better able to exploit such an opportunity.

Table 7.12 Summary table of impacts - Creative Industries

Climate Change variable	Associated Impacts	Potential severity ranking	Employment effects	IPPC uncertainty rating	Current availability of adaption options
Increase - winter rainfall	Flooding - time loss, damage repair	H	M -ve	L	Y
	Risk of flooding - building/urban design for adaption	L	L - ve	M	-
Higher summer temperatures	Relocation - lower skilled labour supply	L	L -ve	M	-
Sensitivity to socio-economic scenarios		Impacts exacerbated under RS scenario			
Key non climate change sectoral drivers of change		Socio-economic development patterns			
Key stakeholders in impact and adaptation analysis		GOL, LDA, GLA; FSB; CBI			

7.12 Summary of Economic Impacts of Climate Change

The preceding analysis of potential climate change impacts enables us to draw the following general conclusions.

- The increased flood risk to areas of London vulnerable to river and drainage flooding from higher rainfall intensities predicted in the climate change scenarios is a significant threat to many economic assets, including property, communication and transport infrastructure and people.
- The indirect costs of a perceived increased flood risk arise from relocation of business and commercial activities to other (global) cities and/or a relocation of highly skilled parts of the labour force. These costs are thought by stakeholders to be as significant as the direct costs. A response to this threat appears to lie in improved flood prevention schemes.
- The future pattern of economic development for London needs to take account of any such increase in flood risk.
- Adaptation strategies for flood prevention are being developed. There is evidence of broad stakeholder involvement in this process though the process is at an early stage.
- Flood risk threats to buildings and infrastructure - along with changing atmospheric conditions associated with a warmer climate - present immediate challenges in building and urban design. These climate change issues do not relate only to London. There therefore appears to be a significant opportunity for London's established creative industries - particularly design and architecture - to capitalise on existing Sustainable City initiatives to exploit this evolving global market.
- The London insurance industry is vulnerable to claims made against damages caused by wind storms and flood events that might require reductions in capitalisation. Any major selling of assets (stocks, property etc.) would have a significant effect on credit availability in the financial capital markets, with negative repercussions for activity in the wider economy. An event that results in insured losses over £1 billion in the UK or globally, (of which the 1987 windstorm was one), may trigger such economic impacts.
- The link between the insurance and financial markets identified in the preceding bullet point ensures that the financial service sector will also be impacted indirectly by climate change related extreme weather events. The size of this impact will be determined by the extent that the insurance sector has been able to pass on risk to other financial instruments. It is believed, (IPCC, 2001), that the policy of portfolio diversification which large financial institutions have will ensure that this risk is reduced and the impact mitigated. This conclusion is not well established and needs to be supported by further research.
- The financial services sector is starting to exploit the opportunities provided by the regulation associated with a carbon constrained future, including work in the implementation of revised accounting guidelines, consultancy in energy related

business strategy, verification of Kyoto Protocol flexible mechanisms implementation. Emerging markets in carbon trading are developing and London is currently well-positioned to become the leading centre for that market.

- The economic costs of disruption to London transport systems was the economic impact most widely identified by stakeholders in the consultation process. Detailed modelling of transport flows to, and within, the city, in combination with climate change model scenarios, are required to accurately assess the likely extent of such costs. Historical analogues of a single weather-related disruption on only one stretch of the rail network suggest costs of broadly £2 million.

- The existing net deficit of water resources for the Thames region is predicted - with a low level of confidence - to be exacerbated by future climate change. Key stakeholders are currently developing and costing strategies to meet such a deficit that will - in time - be expected to result in the adoption of a supply option that increases supply significantly (e.g. a new reservoir). The economic effects of such strategies are not known at present. For example, possible resulting water price increases may be subsumed in negotiations with the water regulator.

- The net balance of change in energy demand as a consequence of climate change in London is not clear. The supply infrastructure network is vulnerable to windstorms and clay shrinkage. The economic impacts of disruption to the power supply for extended periods has not been estimated in quantitative terms but is believed to be significant.

- Manufacturing is subject to disruption of raw materials (e.g. food stuffs) that are supplied from parts of the world adversely impacted by climate change. Consumer prices may then be expected to rise. The same mechanism may result in opportunities for recycling environmental businesses, where the price of virgin raw materials (e.g. rubber, wood pulp) increases and makes recycled substitute products more competitive.

- The net economic impact of climate change on tourism and leisure is uncertain. Revenues may increase as London - and the UK - becomes a more attractive destination in summer relative to those in Southern Europe and elsewhere that are likely to suffer from adverse climate change impacts such as the increased threat of forest fires. However, more trips may be taken from London to escape e.g. uncomfortable heat island impacts.

- Flood risks, transport disruption, and heat island effects are climate change impacts that might result in the relocation of workers, or changes in commuting patterns. These impacts might impact on the supply of labour to London's public administration, and other economic sectors or the relocation of employers.

- Increased general awareness of potential and actual climate change impacts in London is likely to focus policy makers minds on the need to reduce carbon emissions and adapt to such impacts locally and globally in the future.

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8. Summary and Policy Processes

8.1 Introduction

This section provides a summary of the potential impacts of climate change in London along with adaptation options. It also discusses the main policy processes that are or will need to consider the potential impacts in order to plan for them. Finally, ideas for where more research is needed and the opportunities that climate change may present are put forward along with overall conclusions for the study.

8.2 Summary of Potential Climate Change Impacts and Adaptation Options

8.2.1 Potential Climate Change Impacts

The following table summarises the potential impacts of climate change impacts for London.

Issue	Main Points
Increased Temperatures	Increased intensity of the urban heat island effect. This phenomena is caused by the density of buildings in London disrupting cooling air flows and the heat emitted from buildings through air conditioning outlets (i.e. warm air). This increase in temperature will be in addition to the level of warming estimated from climate change. Installation of more air conditioning (AC) could further exacerbate this problem, as more heat is emitted from buildings, especially for those who can't afford AC.
	Higher temperatures may affect the ability of children to concentrate at school.
Flooding	Increased risk of flooding of combined sewer systems during heavy rainfall events, if they have insufficient capacity.
	The Thames Barrier was closed 24 times over the Winter 2000/01. This was because of the exceptionally high river flows combined with the normal high Spring tides. The average number of closures for the Barrier for comparable periods is three.
	There is anecdotal evidence that flooding could be highly stressful to children, some of whom see any subsequent rainfall event as threatening.
	Increased flooding could have financial implications for individuals as well as the insurance sector. The widespread flooding in Autumn 2000 in various UK locations led insurers to review their insurance flood cover in high risk areas.
	There is substantial housing and commercial development planned for the Thames Gateway in the coming decades. Some of this area is low lying, downstream of the Thames Barrier and could be subject to increased flood risk.
	The most significant threat to London arises from tidal surges. The Thames Barrier provides protection from a 1 in 2000 year event, declining to 1 in 1000 by 2030. By 2050 a 34cm sea level rise at Sheerness changes the 1 in 1000 year level to a 1 in 200 year event. By 2100 it is estimated that the Thames Barrier would have to close 200 times a year to protect London from tidal flooding.

Issue	Main Points
	Climate change could reduce the standard of river flood protection through rising sea levels, rising groundwater and/or increased storm magnitudes. Beyond 2050 extreme precipitation events of 30 and 60 day duration could increase in magnitude. By the 2080s the 60 day precipitation event that occurs on average 1 in 10 years increases in magnitude by 10%, whereas the 1 in 20 year event increases in magnitude by 16%. This could bring with it increased risk of disruption and damage to underground infrastructure e.g. London Underground and power and telecommunication lines from flooding. Any increased flooding such as flash flooding due to heavy rainfall events would also affect above ground transport systems. For instance, it has been estimated that disruption to rail services caused by a flooded rail line affecting a London bound train in December 2000 cost more than £1 million.
Water Resources	Increased water demand. Domestic water use could increase as a result of more hot Summers leading to increased garden watering and personal washing. The Environment Agency estimates that outdoor water use will increase public water supply demand in the Thames Region by approximately 50 million litres a day due to climate change. Reduction in annual rainfall due to climate change could affect the availability of water for London. It has been estimated that there could be a decrease in average soil moisture both annually and in the Summer in the South East. Drier soils imply more clay shrinkage, induced subsidence and mains leakage. Drier soils will require more precipitation to induce groundwater recharge and surface runoff. Therefore the length of recharge season could decline by 8 days in the 2050s and 14 days by the 2080s. The scale of the intensification planned for London (700,000 population growth in the next 15 years) could exacerbate this problem in the short term. Increased winter rainfall may result in the swelling of clays Water resources could also be affected by a reduction in water quality due to wash-off being carried down to combined sewer overflows (CSOs) and low summer flows reducing the volume of water for dilution of treated effluent in receiving water courses. Changes in rainfall patterns might result in abstraction licences being granted on a shorter timescale to allow flexibility in planning for the availability of water resources.
Health	Increased extreme temperatures could lead to an increased mortality related to heat stress. It has been estimated that the summer heat waves in 1976 and 1995 were associated with a 15% increase in mortality in Greater London. Reduction in winter cold spell related mortality e.g. hypothermia. A recent Department of Health Report has estimated that, by the 2050s, up to 20,000 fewer deaths might occur in the UK as a whole as a consequence of climate change. Increased pollution episodes. It has been estimated that a 1°C rise in Summer air temperatures is associated with a 14% increase in surface ozone concentrations in London. There could be an average increase in the frequency of pollution episodes of over 4 days a Summer by the 2080s due to increased temperature inversions. This could have impacts on the health of susceptible people. Increased temperatures could increase opportunities for crime as windows and doors are left open longer. Higher temperatures could increase the number of road accidents due to driver drowsiness and increased numbers of people cycling and walking. Higher temperatures could mean that rubbish put out for collection may decay quicker, producing unpleasant odours.

Issue	Main Points
Biodiversity	Increased temperatures (coupled with any lack of availability of water) could result in increased pressure on London's green spaces. Stress on green spaces could also have adverse effects on biodiversity. Increased temperatures and its effect on water resources, water temperatures and river flows could have adverse effects on biodiversity including: • Increased evaporation from waterbodies leading to habitat loss; • Loss of important habitats e.g. saltmarsh and further decline in some indicator species e.g. Water Vole; • Earlier blooming of some species over recent years (records at Kew confirm this). Warmer temperatures in Spring are associated with earlier dates of oak leafing by about 6 days for each 1°C increase; • Populations of certain birds e.g. Wren are strongly related to average Winter temperatures and first egg laying dates are related to Spring temperatures; and • Changes in migratory patterns due to temperature changes have also been observed e.g. a 1°C increase in Spring temperature is associated with a 2-3 day earlier appearance of the Swallow in the UK. London's wetlands are already under threat from altered flood regimes, drainage, groundwater abstraction and development and this could be exacerbated by changes in precipitation and its implications for water availability. Moisture availability is critical to other habitats and studies have indicated that there could be a drying of heathland and adverse effects on beech trees. Other impacts could include: • Increased level of inundation and storm flooding; • Accelerated coastal erosion; • Sea water intrusion into fresh waters; • Excessive nutrients and sewage inputs; • Changes in tidal processes e.g. tidal range, sediment supply; and • Changes in air temperature and rainfall could affect growth of salt marsh plants with secondary effects on sedimentation. Severe storms can have devastating effects on trees. Richmond Park lost 10% of its trees in the storms of 1987 and 1990. Small stocks of veteran trees in the Park are especially vulnerable.
Built Environment	Increased temperatures could reduce comfort of occupants in domestic, commercial and public buildings that could lead to business disruption. Building simulations of a small commercial property in London for possible climate conditions in 2050 found that working conditions would be outside of established comfort levels for 415 hours or 11 working weeks. Failure to address this could result in a longer term problem in attracting employees to London. This could affect particular sectors disproportionately because of their importance to London e.g. financial and business services sector. More resources may be required to maintain the integrity of London's historic buildings and artefacts e.g. internal temperature control to protect fabrics and furnishings. The change in flow patterns in the Thames has already uncovered more extensive archaeological remnants. Whilst this is to be welcomed, as it provides sites of interest, this puts the artefacts at risk. More resources may be required to protect them. Higher wind speeds and more frequent storms may lead to business disruption due to damage to overhead power and telecommunication lines. As buildings in London have been designed for relatively benign conditions, any increased storminess may make them more vulnerable to damage. Again this has implications for the insurance sector (see above). More stormy weather could increase damage to older, historical buildings and may require higher expenditure on repairs and maintenance.

Issue	Main Points
Transport	Increased temperatures on the London underground could lead to disruptions to the network and reduced passenger comfort. This could result in a decline in use of the underground contributing to congestion elsewhere and also leading to business disruptions. Increased temperatures could lead to adverse effects on transport infrastructure e.g. rail buckling, melting of tarmac on roads, runways etc. This can cause disruption to the transport network. More frequent closure of the Thames Barrier and the construction of new barriers may cut off some areas for docking, affecting shipping businesses. Flooding of docks might increase under some conditions, depending on the flood management strategy adopted. Low flows on the River Thames during more frequent dry summers could also affect its navigability with implications for water based freight transport. Reduced snow fall should result in less disruption to transport e.g. road, rail and reduced maintenance costs e.g. reduced need for salting/gritting.
Insurance Industry and Finance	Higher temperatures and drier soils could lead to shrinkage of the clay layer beneath London. This could lead to increased subsidence of buildings and infrastructure (e.g. transport networks). According to the Association of British Insurers, their members already incur costs of nearly £1M a day on average due to subsidence claims. Underground infrastructure e.g. water pipes and telecommunication and power lines could also be damaged, resulting in business and service disruption. Climate induced changes in consumer behaviour are those generally related to temperature change. During the hot summer of 1995, there was a net cost to the retail sector in the UK of over £100 million in total. There was a loss to the clothing and footwear market of over £400 million due to people buying fewer clothes and a small gain for the market for fruit and vegetables due to changes in eating habits. Opportunities for designers to provide literally 'cool' goods and brands - implications for design and styling of clothing, fashion, buildings, cars and other consumer items. Some manufacturing sectors in London that use significant amounts of water e.g. brewing and the automotive sector could be affected by changes in water resource availability and any subsequent price adjustment. Current practice is for insurers to offset underwriting losses from climate change type events on property against their investment income. An increase in severity/frequency of these events will result in falling investment returns and higher insurance premiums. A severe event could trigger selling of assets in order to pay the insurance claims made, having knock on effects on the macro-economy. This process also involves the business and financial sectors and so they too could experience adverse impacts from this process. A growth in greenhouse gas emissions trading schemes presents opportunities for London as a financial centre to provide trading services. A system for greenhouse gas emissions trading is beginning to emerge in the UK. Another sector that may benefit from climate change impacts is the environmental goods and services sector. This includes a range of products and services including renewable energy (solar photo-voltaics, water heating, wind energy generation etc), environmental monitoring, waste management, flood defence and protection, both at the public and private level, including provision of sustainable urban drainage systems (SUDS). Relative price changes between virgin raw materials from overseas sources that could be subject to adverse climate change impacts and more locally sourced recycled material, could increase the demand for recycled materials by manufacturers. Unless appropriate responses are made, adverse climate change impacts in London could affect its attractiveness as a destination for investment in both economic development and individual organisations and companies. However, the scale of this must be measured against the level and effectiveness of action being taken in its competitor cities in response to potential climate change impacts.

Issue	Main Points
Tourism	Increased temperatures could attract more visitors to London, benefiting the tourist sector. However, measures would need to be taken to ensure that the experience of London was favourable in order to ensure that the opportunities are maximised e.g. high quality green spaces, comfortable facilities and transport systems. However, high temperatures could lead to residents leaving London in search of a more comfortable environment on holidays or breaks.
Leisure	There could be a move to a more outdoor lifestyle e.g. open air concerts, cafes and other recreational activities. This could have important benefits such as improved health due to more people taking exercise and increased community interaction. This could be particularly important for children given the current trend to obesity and a sedentary lifestyle.
Emergency Planning	Drier weather could bring an increased risk of fire. However, such events are, in many cases, started deliberately. More rapid fire detection may be necessary as well as educational campaigns aimed at dissuading people from starting fires. Increased flooding (as well as other climate changes such as increased temperature etc) may require additional responses from the emergency services. There is a London Flood Warning Plan that is updated regularly and is considering the potential impacts of climate change. The Government is also considering the legislation and funding for local authority emergency planning at present.
Energy	Less need for winter heating. Financial advantage for bill payers and so could reduce incidences of fuel poverty. More need for cooling and possible increase in use of mechanical air conditioning. Increase in summer fuel bills for bill payers. This could outweigh the decrease in winter fuel bills depending on energy source (e.g. gas or electricity for Winter heating compared to electricity for air conditioning in Summer). Increased temperatures and any associated increase in direct sunshine could make the use of renewable energy system more commercially attractive e.g. solar photo-voltaic panels as facades on high value buildings. Increased wind speeds could benefit the generation of energy from wind turbines.

8.2.2 Climate Change Potential Adaptation Options

The following table summarises the climate change adaptation options for London.

Climate Impact	Adaptation Options
Flooding	Accelerated investment in existing flood defence programmes. Improved flood risk identification, forecasting and awareness. Avoidance of developments in at risk areas or making sure that adequate protection is in place. Use of green/open spaces for temporary water storage to alleviate flooding. These latter two points are incorporated in specific policies in the draft London Plan (see below). Other options to address increased flood risk include: • Improved flood warning systems; • Ensure that adequate resources and systems are available for responses to climate related emergency events e.g. flooding; • Long term planning for managed re-alignment in the Thames Estuary; • Establishment of green corridors on the north and south banks of the Thames and London's other rivers as a flooding buffer zone and creation of areas for habitats and species; • Adjustment of timespan for planning permissions allowing flexibility over future development options in the light of climate change. This would have implications for the users of the development; • Promotion of flood proofing on buildings at increased risk from flooding; • Use/re-creation of natural eco-system buffers; • Use of sustainable urban drainage systems (SUDS); • Guidance on building design and developments that will be able to adapt to climate change should be included in the GLA's planned supplementary planning guidance on sustainable buildings; and • Increased collaboration between government bodies, developers and insurance companies could provide an economic impetus for appropriate, sustainable developments in areas at increased flood risk that need economic regeneration.
Water Resources	Reductions in leakage. Extension of metering. Promotion of water efficient appliances. Development of innovative water resource options. 'Use Water Wisely' campaigns. Restrictions on non-essential use.

Climate Impact	Adaptation Options
Living and Working Conditions	Reducing building densities. Changing building height, spacing and street orientation to increase shade. Improving building and cooling system design including enhancing natural ventilation. Use of trees and vegetation for shading. Use of reflective materials. Incorporation of large areas of vegetation and water features within urban landscape to encourage cooling airflows. Promote measures on the underground to deal with extreme heat situations. Use of pumped groundwater as a cooling medium for the London Underground. Increased use of water transport. Higher insulation levels to protect buildings from increased temperatures and reduce energy use in Winter. Provision within developments of spaces for outdoor activities e.g. shared areas for barbecues and entertainment. Use of groundwater for cooling. The new GLA building uses a borehole groundwater cooling system. Make buildings with AC available to the public during hot spells as a refuge from high temperatures. Use of remote sensing techniques to detect movement due to subsidence. Changes to the frequency of waste collection as higher temperatures may produce more rapid decay and associated odours Some of these measures could be incorporated in the GLA's planned SPG on sustainable buildings.
Air Quality	New fiscal and voluntary initiatives to control emissions (Low emission zones). Traffic restrictions. Improved public transport. Incentives to promote car sharing. Pollution warning services. Inventories of pollution sources. Monitoring of key pollutants and relevant weather variables.
Biodiversity	Development and protection of 'green corridors' e.g. river corridors, to facilitate migration of climate sensitive species Protection of green and open spaces Recognition of biodiversity hotspots with associated protection designation Introduction of new facilities to treat polluted water from CSOs during heavy rainfall. Use of softer engineering solutions to flood defence.
Education	Climate change can be an interesting and informative topic for the curriculum. It covers a range of topics and can be approached quantitatively and qualitatively.

8.3 Tolerance and Equity

8.3.1 Tolerance

With 27% of the population of London being Black and Ethnic Minority, tolerance, positive acceptance of difference and a notion of equity is a highly important 'glue' which keeps London working as a multi-cultural city. In the year ending April 2000, race crime levels in London were as high as the rest of the UK put together (at 63 incidents per day) (Livingstone 2000) noting that London is home to about half the Black and Minority Ethnic polulation in the UK. We cannot, however, identify any direct impacts of climate change upon equity and tolerance. A possible indirect impact would occur if climate change led to a change in migration into or out of of the capital. This effect might be experienced through less tolerance of inward migrants from the UK or elsewhere, due to over-crowding. Such intolerance can also be influenced by the political response. Political pressure may increase to address the issue of increased numbers of inward migrants.

8.3.2 Equity

Climate change impacts will, to some extent, affect different communities in different ways. Clearly those who live in a flood plain are potentially more vulnerable to flooding, but the actual risk depends crucially upon the standard of protection that is provided. It also depends on the ability of the community to adapt to and recover from the flood. A highly detailed analysis would be required in order to determine the actual flood risk in specific parts of London and hence it is not possible in this study to claim that *particular* areas or communities are more vulnerable to increased flood risk from climate change than others.

There is little, if any, evidence to suggest that the *direct* impacts of climate change will be greater for some communities than for others. It is not clear why climate change impacts would differentially affect individuals or communities on the basis on their gender, ethnic origin or socio-economic group. Clearly, there are physiological differences between human beings, such that some will be more affected by high temperature extremes than others. However, such differences occur more at the level of individual physiology than at the community-level. Older and less healthy people are generally more vulnerable to high temperature extremes than younger and more healthy people for example. As we have noted elsewhere, however, the more important effect of climate change upon individual health is the significant *benefits* for the elderly which arise from fewer very cold spells. Given that it is the less well off who suffer most from fuel poverty, climate change will reduce those inequalities which arise from the inability to heat homes properly in the winter.

What is much more important in terms of equity considerations than the direct effects are the *indirect* effects of climate change upon communities. Indirect effects arise because of the knock-on repercussions of climate change and invariably involve some response or adaptation to the perceived impacts of climate change. The notion of 'adaptive capacity' has been developed to describe and understand the ability of different social agents to respond to impacts (Adger 2001). Those agents with a high adaptive capacity will be able to respond more effectively, i.e. with fewer social, economic and environmental costs. Adaptive capacity cannot be defined in a single way, but possession of a sufficient stock of resources is an underlying theme of the concept. Those resources may be financial and material, but they may also be social, intellectual and political. Hence, those with more resources will tend to be less adversly affected by climate change, *contra* those with fewer resources, who have less adaptive capacity and will bear the brunt of adverse impacts. Generally, the poorer will be harder hit by climate change impacts, not because of the direct impacts *per se*, but because they are less able to respond and adapt to those impacts.

'Poorer' here means not just those with less income or material resources, but also those who are have less 'social capital'. Individuals in more fragmented communities with few social linkages between individuals typically have less social capital than closely knit communities. Where strong communities exist, there is much more likely to be better information flow and support structures which allow a rapid and inclusive response to events such as floods or heat waves, including early warnings and ameliorative actions, than in more fragmented social networks. Put simply, neighbours who know each other are much more likely to warn one another about impending risks and to help one another respond. They are also likely to be more aware of individuals and families who are most vulnerable, e.g. the elderly or single parents or those whose first language is not English, and can prioritise assistance to them (or at least alert the emergency services).

We have alluded at many points in this section to the inequalities which may emerge due to the differential ability to adapt on the part of different communities and sections of society. How exactly individuals might respond in the 2050s depends upon the wider context of socio-economic conditions, regulations and cultural expectations; hence we have embedded the responses within the socio-economic scenarios. For example, under the Global Markets (GM) scenario, the more affluent will be able to install air conditioning in response to warmer conditions within buildings, which will then increase the problem for those who cannot afford to purchase AC units.

8.3.3 Case-Study: Flooding and Associated Insurance Costs

Climate change impacts could increase the costs of property insurance in London by raising premiums in flood and land subsidence risk areas to cover a higher premium.

Alternatively, if no differentiation of risk areas is undertaken, then general premiums might be raised to cover increased risks in specific localities. A typical UK premium in low flood risk areas is £300 (though crime loadings in London will usually result in higher figures in the capital). In high flood risk areas, the premiums could be several orders of magnitude higher. The ABI comment that:

> *"the impact of such [premium] increases would be to reduce the level of protection afforded to low income households either because they can no longer afford insurance or because they must find the first £2,500 - £5,000 of each subsequent flood claim" (ABI 2002).*

Even without any change in premiums there are significant costs associated with flooding, due to the fact that 25% of households choose not to insure their contents, this number rising to 50% for low income groups (ABI 2002). One of the key factors which limits uptake of insurance amongst low-income groups is the price (ibid). Furthermore, the ABI considers that many households and businesses are currently underinsured (an informal survey in Lewes, East Sussex, (which was seriously flooded in November 2000) suggested that 15% of residents were underinsured by between £5,000 and £20,000) (ABI 2002). Considering that flood claims are typically of the order of £15,000 to £30,000 on a household policy (ABI 2002), it is evident that the costs of *not* being properly insured are significant and will increase social inequality (because the less affluent are less well insured). There are a large number of basement flats in

London, as a consequence of the high value of property, and these conversions are particularly vulnerable to flooding especially since many such flats are rented-out and hence flood protection measures are less likely to have been installed by the owner. (Basements in some older properties have traditionally been designed to cope with flooding and groundwater intrusion). Occupiers of rented basement flats are likely to be amongst the less affluent, will have less insurance cover and hence the incidence of floods could increase the existing pattern of inequalities.

Already insurance companies are removing automatic flood risk protection from properties in vulnerable areas of the flood plain. The ABI has entered into a two-year agreement with the government to maintain cover for existing domestic properties and small business policy holders, but at the time of writing this is due to run out at the end December 2002 (ABI 2002). In June 2002, the first British insurer stated in public that it would no longer insure those living in areas at high risk of flooding. The company E-Sure estimate that the effect of covering flood-risk areas adds 5 to 10% onto the costs of all policies, such that excluding cover of such risks would save an average of £30 per dwelling per year across the board. Properties in flood risk areas in London could be affected quite soon if insurance cover is withdrawn. Such a policy change would have repercussions on property values and insurance premiums and/or could lead to certain risk being reclassified as uninsurable with subsequent withdrawal of coverage. Conversely while properties in flood risk areas may suffer in this way, many households not at risk of flooding might benefit financially from any move in the insurance industry toward exceptional provision of flood risk cover.

Higher flood risk insurance costs would reduce the availability of insurance for spreading risk, potentially increase the percentage of households without cover and increase the demand for government-funded compensation following natural disasters. In the event of such changes, the relative roles of public and private bodies in providing insurance and risk management resources can be expected to be re-examined.

8.3.4 Scenario Differences

In the GM world, private insurance cover would be the norm, but with much greater differentiation of the potential risk, i.e. less spreading of flood risk across all household premiums. Hence, those with property in high flood risk areas would find that their premiums would be much higher than for the average property and this would cause price reductions in areas where flooding occurred relatively frequently. High climate change combined with high premiums would accentuate property blight. More private provision of flood defences would limit payment of premiums to those households lucky enough to be situated behind adequate defences. Households in less well protected areas, and without sufficient resources to pay insurance cover, would suffer, both from the increased risk of, and vulnerability to, flooding and the lack of insurance protection should flooding take place.

Under GM, the better-off could simply pay increased insurance cover. The ‘insurance deficit’ between rich and poor would increase and flooding would come to affect a larger proportion of the less well-off than presently. There would be more paid-for investigation of the flood and subsidence risks associated with potential property purchases, though also more legal challenges to uncertain information about flood risks in GM. Such legal challenges might act to reduce the public provision of flood risk information where uncertainties remain. The differential responses to climate change due to differences in adaptive capacity would accentuate the existing inequalities within society.

In an RS world, the principle of sharing out the risk across a large number of households would be maintained. The government would step in to assist households which are flooded and do not have insurance cover, though the economy could not support large hand-outs. Information on flood and subsidence risk would be included as part of the local search associated with any new house purchase. Public policy would aim to limit any increase in inequality arising from enhanced flood risk. There would also be stronger communities and denser social networks in the RS world than currently, hence generally more social capital available; this would tend to address inequalities more effectively than in the GM world.

The table below summarises the key impacts upon equity which we identified in earlier sections.

Table 8.1 Summary of Possible Effects upon Equity Arising from the Indirect and Direct Impacts of Climate Change

Impact Area	Possible Increase or decrease in equality	Description of Impact
Individuals: Winter heating	Increase	Less need for heating in winter will benefit the health and incomes of those in fuel poverty (= the less well off)
Domestic buildings: Summer Cooling	Decrease	Wealthier will be able to pay for air conditioning or other cooling techniques, increasing waste heat in local environments
Commercial buildings: Summer Cooling	Decrease	Wealthier firms will install AC or other forms of cooling, increasing waste heat in local environments of other buildings who cannot afford cooling or wish not to. Those in overly hot offices and factories could suffer adverse health impacts.
Households: Insurance	Decrease	The less affluent are less well protected by insurance and will be more adversely affected by increasing insurance costs and subsequent flood or subsidence episodes. The less affluent are possibly less likely to pay for information relating to the flood or subsidence vulnerability of a property prior to purchase. More basement dwellers (more exposed to flood risk) are likely to be less affluent. Expensive private development could be accompanied by high quality flood protection, in contrast to less expensive development.
Households: Outdoor spaces	Decrease	The less affluent are less likely to have their own outdoors space for use in hot weather. They will be more dependent upon public open spaces. Also opening windows and doors for cooling purposes brings with it a higher risk in more crime-prone areas.
Households: Water prices	Decrease	If water shortages occur, the less affluent could be more exposed to increased water pricing to households.
Households: Over-crowding	Decrease	Those who suffer from over-crowding in their homes will be most vulnerable to extreme heat episodes and to any increase in the incidence of infectious diseases.
Individuals and communities: adverse health impacts	Decrease	The adverse impacts of climate change upon health will be felt most acutely and with greatest consequence by the underprivileged

Impact Area	Possible Increase or decrease in equality	Description of Impact
Individuals and communities: heat stress	Decrease	An increase in heat related deaths and illness episodes would particularly affect the elderly, sick and those without access to air conditioning or other forms of cooling.
Individuals and communities: crime	Decrease	At times of disruption (such as flooding) opportunistic crime can increase. This is likely to be greater in areas that are already more prone to crime.
Individuals and communities: lifestyle changes	Increase	More active, outdoors lifestyles and healthier diets consisting of fresh fruit and vegetables could both be more feasible across the social spectrum. The least well-off would probably benefit the most from such changes.

8.4 Climate Change and Policy Making for London

There are a number of policy processes that are ongoing in London that will need to consider the potential impacts of climate change. Many of these have been explored in the preceding sections. This section summarises the main policy processes and the nature of the climate change issues related to them. It makes recommendations on how climate change should inform further policy and strategy development.

The main strategy, policy and planning processes related to climate change in London include:

- The draft London Plan - the spatial development plan for London;
- The London Development Agency's economic development strategy;
- The Environment Agency's strategic processes including those for water resources, flood defence and water quality;
- Water companies' planning processes; and
- Others including local authorities, the Thames Gateway London Partnership, the Thames Estuary Partnership and the London Biodiversity Partnership.

These are examined in more detail below.

8.4.1 The Draft London Plan

The Greater London Authority's spatial development strategy 'The draft London Plan' puts forward policies that set the framework for land use and related issues in London for the next 15-20 years. The Plan is at the draft stage and the public consultation phase closed on 30th September 2002. Once published, boroughs' unitary development plans must be in 'general conformity' with the Plan. The Plan estimates that the following could characterise London by 2016:

- Population is projected to reach 8.1 million, 700,000 more than today. The make up of London's population is projected to change with more young people, many more people from black and minority ethnic communities and more young newcomers from across Europe. The risk of climate change related impacts affecting the present level of population is increasing. With the steep rise in the population this could mean that even more people could potentially be affected in the future;

- A minimum target for new housing of 459,000 dwellings. This could represent a further intensification of development leading to exacerbation of the heat island effect and difficult choices about the location of development. For instance 30% of the housing allocation is for East London, some areas of which are at increasing risk from flooding; and

- Economic growth could provide up to 636,000 additional jobs. However, disparity between rich and poor has increased. Nearly 40% of this growth is expected to be in East London, including the City and the Isle of Dogs. This is the highest proportion of the projected growth. Certain economic sectors could be particularly vulnerable to climate change impacts as they are expected to provide a high proportion of economic growth in the future and have a requirement for significant associated development e.g. the growth in the financial and business services and its demand for more office space.

The main spatial priorities that are relevant to a consideration of climate change impacts are:

- Development in Central London will intensify and accommodate substantial growth, especially in economic activity; and,

- Major development to the east of London along the Thames Gateway with an expansion of some central London functions into the city fringe, Isle of Dogs and Stratford.

Climate change is only one of a number of changes that London will be facing over the coming decades. The potential impacts of climate change will need to be considered throughout the draft London Plan process. The draft Plan has a number of policies that refer to or that are directly relevant to climate change, its impacts and potential adaptation measures. These include polices on:

- Climate Change (Policy 4A.13). The policy states that "The Mayor will and boroughs should assess and develop policies for the likely impacts of climate change on London in light of the outcome of the work by the London Climate Change Partnership…". The remainder of the policy relates to flood risk and the supporting text for the policy highlights that a significant proportion of future development will be in East London, which could be increasingly at risk from tidal flooding.

- Sustainable design and construction (Policy 4B.6). The Mayor will work with partners to produce Supplementary Planning Guidance (SPG) on sustainable design and construction. This policy has the ability to address many aspects of the quality of the built environment under conditions of climate change including vulnerability to storm and flood damage, subsidence, user comfort under elevated temperatures and energy use. Ensuring that climate change related issues are addressed in the SPG would be one mechanism for improving the performance of the built environment under potential climate change.

- Biodiversity and nature conservation (Policy 3D.12). The Mayor will work with partners to protect, manage and enhance biodiversity in support of the Mayor's Biodiversity Strategy. The potential climate change impacts on biodiversity are examined in preceding sections. It is recommended that potential climate change impacts and appropriate adaptations are a significant feature of the development of the Mayor's Biodiversity Strategy.

- Realising the value of open space (Policy 3D.8). The Mayor will work with boroughs and other partners to protect and promote London's network of open space. Open spaces will become even more important to London under anticipated climate change. They will be put under even greater demands from elevated temperatures, reduced availability of water and fire risk during long dry spells. However, if developed properly, they could act as a refuge from elevated temperatures and poor air quality, providing a cooling breeze, some tree cover and opportunities for a more outdoor focused lifestyle. Community focused activity such as festivals and concerts could be come even more common, if suitable provision were made for increased public open spaces. In some circumstances, open spaces could act as temporary flood storage, although this would need to be managed to ensure that public safety was not compromised. Appropriately managed and maintained open and green spaces could provide valuable habitats for London's species. These aspects of open and green spaces have been explored in the preceding sections. Climate change impacts and adaptation options should be incorporated in polices and programmes for open spaces.

The Blue Ribbon Network consists of London's systems of rivers, canals and water bodies. The Mayor has produced a strategy for the Blue Ribbon Network. This replaces RPG3b/9b (Strategic Planning for the River Thames). A number of policies that could be affected by climate change come under the Blue Ribbon Network Strategy including:

- Flood plains (Policy BR5). Boroughs should identify areas at risk from flooding (flood zones). In particular, boroughs should avoid permitting built development in functional flood plains. In other areas of flood risk a flood risk assessment should be carried out. This will influence the location and design of proposed development. This is a key policy from a climate change perspective. Given the anticipated demand for new housing and growth in business premises needed for the anticipated economic growth in the next 15 years, this policy will need to be successfully implemented in order to ensure that inappropriate development i.e. that at major risk from flooding or with a lack of appropriate flood protection or not adapted to flooding, does not occur. The draft London Plan has a specific policy on encouraging sustainable urban drainage systems (SUDS) on developments (see below). Their success will depend on the physical characteristics of the site as well as specific development proposals. There is no doubt that SUDS could play a role in managing flood risk in London, along with other flood management techniques (see below).

- Flood defences (Policy BR6). For locations adjacent to flood defences, permanent, built development should be set back from those defences to allow for the replacement/repair of the defences and any future raising to be done in a sustainable and cost effective way. The supporting text for the above flood related policies also states that as built development is to be avoided on floodplains, there may be scope for renewable energy developments such as wind turbines.

- Sustainable drainage (Policy BR7). The use of sustainable urban drainage systems should be the norm unless there are practical reasons for not doing so.
- Rising groundwater (Policy BR8). In considering major planning applications in areas where rising groundwater is an existing or potential problem, the Mayor will and boroughs should, expect reasonable steps to be taken to abstract and use that groundwater. The water may be used for cooling or watering purposes or may be suitable for use within the development or by a water supply company. The supporting text for the policy refers to the General Aquifer Research, Development and Investigation Team (GARDIT) project that is examining ways of abstracting and using groundwater again. A strategy has been put in place to ensure that groundwater is maintained at levels which do not threaten the stability of, or flooding to, vital infrastructure.
- Water supplies (Policy BR9). The Mayor will work in partnership with appropriate agencies to protect and conserve water supplies in order to secure London's long term needs. The supporting text for this policy states that the pressure on water supplies is likely to increase due to climate change. This could occur because of changes to rainfall patterns and the availability of water resources at particular times of the year. Elevated temperatures could also result in changing demand for water for domestic and commercial uses.
- Water quality (Policy BR10). The Mayor will and boroughs should seek to protect and improve water quality to ensure that the Blue Ribbon Network is healthy, attractive and offers a valuable series of habitats. This policy is helpful in supporting measures to improve water quality. Specific actions taken by the EA and water companies as well as the impacts of climate change on water quality are described in separate sections below.
- Water and sewerage infrastructure (Policy BR11). The Mayor expects developers and local planning authorities to work together with water supply and sewerage companies to enable the inspection, repair or replacement of water supply and sewerage infrastructure, if required, during the construction of development. The Mayor will work with Thames Water, the Environment Agency and other relevant organisations to ensure that London's drainage and sewerage infrastructure is sustainable. See below for a discussion of the relevant policy framework for the EA and water companies.

Overall the policies for the Blue Ribbon Network are helpful in relation to climate change and should allow appropriate action to be taken including adaptation.

The draft Plan also refers to the present study, the work of the London Climate Change Partnership and a forthcoming study on climate change adaptation stating that the policies of the Mayor and other planning authorities should adapt to the finding of the study. This is encouraging but much work remains to be done on the potential impacts and adaptation options for specific developments. A number of actions should be considered in relation to the draft London Plan and climate change:

- A review of the polices to ensure that they have incorporated potential climate change impacts and responses. The present study will inform that process. This may lead to the need for additional polices or modifications of existing ones; and,
- An effective review process to ensure that climate change related policies are implemented and monitored for their effectiveness.

The draft Plan underwent a sustainability appraisal. This was an opportunity to highlight climate related issues, amongst a wide range of objectives, and helped to feed climate change issues through to the development of many of the above policies. The Plan will operate up to 2016 but it is acknowledged that a longer term perspective needs to be adopted as many of the development decisions taken now will have implications far beyond the Plan period e.g. transport infrastructure takes many years to design and build. In examining the longer term perspective through the use of alternative scenarios the Plan states:

> *"…The imperative of sustainable development will grow even stronger as problems such as climate change become inescapable…"*

The recognition of the long term nature of climate change issues in the draft Plan is encouraging. This needs to continue and feed into supporting effective long term planning and appropriate responses. The forthcoming study on climate change adaptation options for London will be an important first step in considering appropriate responses. As the remainder of this section shows, there is already much work that is being done that can support a robust approach to long term planning. The London Climate Change Partnership should play a key role in this area.

There are a number of other strategies that the Mayor has or is producing including:

- Transport;
- Economic Development;
- Biodiversity;
- Air Quality;
- Municipal Waste Management;
- Ambient Noise;
- Culture;
- Energy;
- Children.

Some of these could be affected by climate change impacts e.g. air quality, economic development and biodiversity. Others have a role to play in reducing the greenhouse gas emissions that contribute to climate change e.g. energy and transport. The majority of these have been used to inform the sections on social, economic and environmental impacts in this report. Various agencies are responsible for producing and implementing these strategies e.g. London Development Agency for economic development and Transport for London for transport infrastructure. A discussion of their role forms part of the preceding sections. The analysis below looks at their main policy roles.

8.4.2 London Development Agency

The London Development Agency is a functional body of the Greater London Authority and is responsible for:

- Furthering the economic development and regeneration of London;
- Promoting business efficiency, investment and competitiveness;
- Enhancing and developing the skills of local people; and
- Contributing to sustainable development.

London's economy seems set to experience some significant changes in the coming decades. As was discussed above, it is estimated that London's economic growth could result in up to 636,000 additional jobs by 2016. Nearly 40% of this growth is expected to be in East London, including the City and the Isle of Dogs - an area at risk from increased flooding. Continued growth is expected in financial and business services with around 440,000 further jobs (the most significant contribution to economic growth - over 50% of the total new jobs), along with distribution, hotels and catering, retailing, health and education and other service sectors. The public administration, primary/utilities and manufacturing sectors are expected to decline. It is thought that because of these dynamics, the financial and business services sector could be vulnerable to certain constraints such as undersupply of office accommodation, lack of suitably skilled employees, inadequate transport and other infrastructure e.g. ICT and poor environment. As has been discussed in previous sections these could be exacerbated by climate change. It has been estimated that London could require 7-9.2 million square metres of new office space by 2016. The current stock is 26.7 million square metres. This is between a 26 and 34% increased in office space - a further intensification that could contribute to increases in the climate related phenomena such as the urban heat island effect. It is clear that climate change could have significant impacts on key economic sectors including:

- Business interruptions due to infrastructure disruption e.g. flooding and elevated temperatures affecting roads and rail and subsidence and soil shrinkage disrupting power lines, ICT linkages.
- Deteriorating working conditions due to elevated temperatures and reduced air quality exacerbated by increases in the urban heat island effect. This could lead to reduced productivity and a reduction in the ability to attract and retain suitable employees who might prefer to work in a more attractive environment.
- Reducing attractiveness of London as a business location leading to a reduction in investment in London in preference to other cities that are either less vulnerable to climate change or have invested in the necessary adaptations.
- Changing flooding patterns could affect or restrict the location of developments or increase their costs because of the need for flood management provision. A large proportion of the estimated development is expected to occur in East London, an area that could be vulnerable to increased risk from flooding.
- Specific sectors may need to make significant investments in climate change related infrastructure e.g. water companies, local authorities and the EA.

- Business costs could rise substantially due to rising costs of insurance for developments at risk from flooding and storm damage. One response could be to ensure that developments were designed and constructed to withstand potential climate change impacts.

All the above points to a need to consider the potential impacts of climate change on the present and future economy of London. As London represents a significant proportion of the UK's economic activity and hence has wide reaching influences, it is doubly important that serious consideration is given to potential climate change impacts and that these form part of the London economic development strategy. As has already been discussed there could be significant opportunities for economic development in emerging sectors such as the environmental industries sector and other more established sectors of the London economy such as tourism. Studies are already being undertaken to asses the potential of environmental industries in London and the South East and what support would be required to nurture their growth. The Environment Agency

The Environment Agency (EA) is responsible for environmental regulation and related issues. The following comments are based on discussions with Agency staff. The issues of particular relevance to consideration of climate change impacts include:

Water Resources

- The EA has produced a Water Resources Strategy for the Thames Region that includes London. It states that a high proportion (55%) of the effective annual rainfall is already used for water supply. 86% of this is for public water supply.

- The supply-demand balance in London is in deficit at present by approximately 180Ml/d. Using the rising groundwater in London as a resource could supply 30-50Ml/d but other schemes could help bridge the gap. Water resource management measures are essential to deal with both demand increase and some of the potential impacts of climate change. Sustainable management of water on London includes such measures as urban drainage, rainwater re-use, metering, tariff development, leakage control, water conservation in private households (low flush/dual flush toilets, water butts, grey-water use), water re-cycling in industry, re-use of water in climate control systems and pressure and flow management of taps in commercial premises.

- Without further action to manage demand and reduce leakage, new strategic water resources may be required under certain scenarios by 2020 for London. Metering and new, innovative tariffs will be essential to manage the pressures and costs of water and protecting the environment if, and when, climate change impacts start to take effect.

- The Thames Region Water Resources strategy used a range of scenarios that included potential climate change, to inform the development of the strategy. However, more work needs to be done to consider the impacts at the catchment level. The EA is developing Catchment Abstraction Management Strategies to assess the total amount of water available in a catchment and develop a strategic plan for supply and demand. Another process - the "Restoring Sustainable Abstraction" programme is assessing other ways of obtaining water for supplying needs in particular areas. Both of these processes should be informed by the present study as well as seeking further ways of assessing the potential impacts of climate change on water resources for London. Statistical downscaling techniques could deliver the local, catchment scale scenarios needed to undertake these investigations.

Water Quality

- As discussed in the environmental impacts section, a key issue for the impacts of climate change on water quality in London is the capacity of its combined sewer systems. These were designed and constructed for certain conditions and climate change may result in significant changes in the quantity of water they have to carry e.g. under heavy rainfall events that may lead to flooding. The EA, Thames Water and others are carrying out an assessment of current capacity and the various proposals for increasing this. This will assess the various solutions being put forward to the problem of capacity. It is intended that it will be completed for the next round of water company investments - Asset Management Plan 4 (AMP4 - 2004). It is a £5M project, over 5 years and has been running for about a year so far. It is unclear at present how OFWAT propose to assess the impact of climate change on water company investment needs in AMP4. Also it is important to ensure that any solution to combined sewer system capacity does not result in increased energy use e.g. for pumping, to the extent that long term environmental objectives elsewhere are impeded. It would be useful to assess this as part of the project, if possible. An example of this approach is the UKWIR project that is examining waste water treatment technologies, their ability to meet more stringent water quality standards and the implications for energy use and greenhouse gas emissions. There are a range of treatment technologies with various greenhouse gas emissions profiles. Use of renewable energy for any increased energy demand could help to reduce emissions. This could be beneficial for a number of areas. Renewable energy is not subject to the climate change levy and it could create more demand for the development of renewable energy.

- With regard to other aspects of water quality, EA river water quality objectives (RQOs) are already heavily influenced by discharges from sewage treatment works. The EA are already planning for low flows and hence low dilution that could occur under conditions of climate change. This is discussed in the previous section on the potential impacts of climate change on the environment.

Flood Risk Management

- The EA, working with a range of partners, is developing a strategy for flood risk management in the Thames Estuary for the next 100 years. "Planning for Flood Risk Management in the Thames Estuary" covers the tidal Thames and its natural floodplain from Teddington in west London to Sheerness/Shoeburyness in the outer estuary.

The Project aims to:

- Assess and understand the tidal defences in the context of the wider Thames Estuary setting. This includes assessment of the residual useful life of the defences together with an understanding of the 'drivers' including climate change, urban development, social pressures and the environment.

- Inform and gain the support of political and funding partners and stakeholders; and
- Prepare and manage a programme of studies linked with consultation, leading to a strategy for flood risk management in the Thames Estuary for the next 100 years.

The project will take five years to complete and involve research to build up a detailed understanding of the physical processes affecting the Thames Estuary. Again, statistical downscaling techniques could be used to develop scenarios of tidal surges that compliment existing work with physical models of the estuary.

Development and Flood Risk

As part of its role in the permitting and regulation of flood management and related issues the EA has been assessing its approach to development and flood risk. PPG25 suggests allowance should be made for climate change. Recent research has led to the incorporation of an allowance of 20% extra fluvial flow over a 50 year period, based on Thames and Severn (Environment Agency). By contrast allowance for sea level rise has been a consideration for the past few decades. PPG25 currently quotes 6mm per year although during the design in the 1970s of the current tidal defences for the Estuary, a figure of 8mm per year sea level rise was used. The EA is considering two main issues at present:

- A project to assess whether 20% is an appropriate figure for all watercourses, or should this be adjusted up or down based on such factors as urbanisation, catchment size and geology; and
- Can more refined guidance be developed based on the smaller grid size of the UKCIP 2002 scenarios compared to UKCIP 1998, e.g. a regional London & South East figure rather than an England figure?

Both of these issues concern accuracy and reliability of current information. Other issues being considered include:

- Will flood defence standards decline with time (i.e. 100 year standard becomes 50 in the future etc).
- Should defences be upgraded to maintain the current standard or accept a lower standard in future? The latter option would increase the flood risk at a site, which may alter the PPG25 risk category, and hence restrict future options for development.
- Adding 20% to flows enlarges the floodplain, though not necessarily by 20%, the figure will vary with topography. In areas not at risk now, but at risk in 50 years, there could be a series of options: (a) do nothing, (b) object now or (c) ensure a design that allows for changing risk, e.g. raise floor levels to cope with future flood levels. Should the same option be chosen everywhere, or should it be varied depending on location/development type or lifespan?
- Planning policies which reflect the changing risk associated with climate change need to be developed with Local Authorities, GLA etc.
- Flood risk assessments for PPG25 need to include climate change, including work for strategic sites such as the Thames Gateway.

- Could developers contribute toward flood mitigation costs on sites that are well protected now but perhaps not in future? The defences may need replacing or upgrading e.g. Lee Valley. EA NE Area Thames is currently undertaking a modelling exercise on the River Lee Flood Defence Channel (RLFDC) to ensure it can cope with the expected 20% increase in flow during storm conditions. Findings are expected during 2002 and decisions on whether the capacity needs to be upgraded will be taken after this time.
- Can surface water systems cope with increased storminess and how can this be incorporated in design, maintenance and upgrading? SUDS, which may be appropriate in some circumstances, offers scope for easier upgrading than fixed pipe sizes, unless they are oversized now and hence will be able to cope with increased flows in the future.
- Can SUDS be retrofitted to locations to assist in strategic surface water management?
- The EA grants consent for culverts etc. Should these consider the 20% extra flow expected to be carried? This should be a policy decision.
- What is the best way to communicate all these issues especially where they may affect sensitive issues such as house purchases?
- What is the best way to begin to raise awareness of potential flood risk and any mitigation needed? A 1 in a 1000 year (0.1%) event is a high standard but it could fail or be overtopped, especially under climate change conditions. Do we start warning existing development which is at high flood risk, because of a high flood impact (risk = probability x impact) or which has high damage impact potential e.g. due to computers in basements, or residential accommodation below high water level?

The EA has or is commissioning two projects to address the last two issues. One is examining methods for communicating flood risk and the other is examining the socio-economic impacts of flooding.

Consideration needs to be given to the widespread application of construction methods that can deal with flood risk, where development in flood plains is considered to be acceptable. This could include elevated floor levels, access routes, construction materials and flood protection devices.

The EA NE Area and SE Area (Thames), who are both involved in managing the tributaries to the Thames such as the Wandle, Brent and Crane, Colne etc., are developing Catchment Flood Management Strategies for the river catchments that feed the Thames. These will be ready by the end of 2003/04 and implementation will follow.

The above processes operate mainly at the national and regional level. There are some more local process e.g. Local Contributions (these supersede the Local Environment Agency Plans) that identify local environmental priorities and actions. It is at this local level that the impacts of climate change need to be understood in more detail in order to formulate appropriate actions. As well as the strategic processes identified above, the EA is contributing to a number of climate change related projects including:

- A project with partners in the South East and Europe called European Spatial Planning Adapting to Climate Events (ESPACE). Part of this will be the development of a Decision Testing Tool to see how decision making will stand up to the impacts of climate change.
- The Thames Regional Climate Change Impacts study (WS Atkins, July 2001) that identified a number of priority actions for the EA:
- Thames Estuary – develop baseline scenario and understand impacts of climate and social and economic change on the estuary including impacts of combined sewer overflows (CSOs) on the estuary under climate change;
- Review effect of climate change on current level of flood defence;
- Assess costs and benefits of maintaining target standards in the face of climate change;
- Develop appropriate wildlife corridors;
- Manage habitat change rather than preserve designations; and
- Further development of regional water resources modelling.

As can be seen from the above many of these actions are being taken forward or have strategic processes associated with them that have the ability to integrate climate change into policy development. However, the approach is not yet comprehensive and all these initiatives need to feed into strategies and plans in order to identify and secure the necessary actions and resources. There is also a need for maintenance of high quality monitoring systems and long term, homogenous observational records to measure and help in the assessment of climate change. The EA is identifying climate change R&D needs to support its strategic and planning processes including:

- The likely impact of either low flows during drought periods or violent storms on the geomorphology and hydrology of London's rivers. The sedimentation patterns of rivers are dependent upon flow, deposition will occur in slow moving water and high flows are likely to deepen the channel. It would be useful to add investigation of erosion and accretion in the estuary to these studies; and
- The impact of climate change on water quality due to changes in dilution, dispersal and degradation of chemicals and pollutants in the water. This could in turn affect discharge consents to the water environment.

Both the above have significant implications on the ecology of the river, smothering plants and animals or preventing colonisation by plants and recruitment of invertebrates and fish and preventing the ability of the rivers to sustain life.

This R&D will support the EA's strategy and policy development.

8.4.3 Water Companies

Water companies have a statutory duty to provide a safe and reliable supply of potable water and to maintain the water mains system and to reduce leakage. They also have a duty to consider recreation and conservation. Thames Water is additionally responsible for collecting and treating waste water, for collecting trade effluent and maintenance of the sewer system.

The potential effects of climate change on water companies' business can include the following: reduction in quantities of both groundwater and surface water available for abstraction; lower flows in rivers leading to reduced effluent dilution; additional stresses on mains and sewage networks due to increased ground movement; increased amounts of sewage effluent during storm events; and increased and higher peak demands during hot weather.

Water companies take account of climate change in the planning process as part of their overall approach to business risk. Companies put contingency plans in place to ensure the maintenance of services given the expected climate change impacts. This is because the time scales necessary to undertake major capital construction schemes involve taking decisions now, which may not lead to completion of the scheme for another 20 years, when climate change impacts may be more fully realised.

The potential impacts of climate change on the requirement for new developments e.g. water resources, wastewater treatment and the management of existing assets, is informed by water industry research and regulatory requirements. The UK water industry research group (UKWIR - funded by water companies) is carrying out a number of climate change related projects including:

- Phase III of a study examining the impacts of climate change on water quality. This phase will develop modelling tools; and
- A study on the hydraulic capacity of sewers.

The outcome of these studies will be used to inform water company asset development plans. However, in relation to water resource requirements, more research needs to be carried out on the relative significance of catchment land use and climate change.

Other research projects funded by water companies are addressing amelioration of climate change impacts. One example is Thames Water's Thames Tideway Strategic Study which is currently assessing the environmental impact of storm sewage discharges to the tideway and is also considering what improvements (and associated costs) may be desirable with a view to developing technical solutions. This study recognises that climate change predictions for more frequent storms could aggravate water quality problems.

8.4.4 Local Authorities

London's Local Authorities have a key role as community leaders and service providers. Many have, as part of their Unitary Development Plans and Local Agenda 21 strategies, addressed some of the issues raised by potential climate change effects. Local authorities work with key stakeholders, public sector agencies and business and have a key statutory role in a number of areas which may be affected by climate change including transport, the environment and housing.

Local authorities provide a range of services that could be affected by climate change including:

- Social services including those for people with disabilities and the elderly;
- Land use planning and development control. The strategic planning aspects of this role and the implications of climate change are explored above for the GLA;

- Waste management including collection, disposal and recycling;
- Fire and rescue;
- Emergency planning - co-ordinating responses from the emergency services to disasters such as flooding;
- Roads, highways and transportation including the provision, management and maintenance of roads;
- Ensuring local housing needs are met; and
- Environmental health including food safety and pollution control.

London's local authorities have a key role as community leaders and service providers. Many have already started to address climate change issues in their Unitary Development Plans as well as in their community and Local Agenda 21 strategies. They have a key statutory role in implementing strategies in a number of areas affected by climate change such as housing, transport and the environment.

8.4.5 Thames Gateway London Partnership

Thames Gateway London Partnership is a sub-regional alliance of thirteen local authorities, five universities, the Learning and Skills Council London East and the London Development Agency working together with the private sector, local communities and strategic agencies to deliver the economic, physical and social regeneration of the Thames Gateway in London. It is Europe's largest and most ambitious regeneration initiative and extends from Tower Bridge eastwards to Thurrock and Dartford. They are involved in a number of developments relevant to climate change including partnerships with the EA, GLA and Thames Estuary Partnership including contributing to the 'Planning for Flood Risk Management in the Thames Estuary' project.

8.4.6 Thames Estuary Partnership

Thames Estuary Partnership (TEP) was formed to integrate the wide range of uses and interests on the Thames Estuary. It has a mainly environmental focus and has produced the Management Guidance for the Estuary which fulfils the role of the EA's Local Environment Action Plan (LEAP). It covers the Thames from Tower Bridge to Shoeburyness on the north side and Isle of Grain on the south side. The Thames Estuary Research Forum is part of the TEP and seeks to address the research priorities for the estuary such as biodiversity, fisheries, flood defence and physical dynamics, recreation and access and water quality. The Thames Estuary Partnership is working with the Environment Agency who have initiated the "Planning for Flood Risk Management in the Thames Estuary" project. This is a partnership project involving a range of organisations, developing a strategy for flood risk management in the Thames Estuary for the next 100 years. The project covers the covers the tidal Thames and its natural floodplain from Teddington in west London to Sheerness/Shoeburyness in the outer estuary.

8.4.7 London Biodiversity Partnership

The London Biodiversity Partnership has produced a series of habitat audits and species and habitats action plans. The ones of most relevance to a consideration of climate change impacts are covered in the section on potential environmental impacts.

8.4.8 DTI Foresight

The Foresight initiative is developing a project on flood and coastal defence. Its aim is "to produce a long-term vision for the future of flood and coastal defence which takes account of the many uncertainties, but which is nevertheless robust, and which can be used as a basis to inform policy, and its delivery. In common with other Foresight projects, the vision produced should be challenging and independent." The outcomes of this study may be helpful in informing the strategy and planning processes relevant to climate change in London.

8.4.9 Concluding Remarks

Many of the key strategic and policy processes have begun to consider the potential impacts of climate change. Awareness of climate change issues amongst stakeholders involved in this study was high and is accelerating. However, most of the strategy and policy responses are of a scoping nature and more work needs to be done to begin to quantify the potential climate change impacts and adaptation options at the local level including impact on water resources, employment, flooding, water quality, settlement patterns, working conditions, open spaces, infrastructure, biodiversity, economic sectors, health and the built environment.

8.5 Further Research Requirements

A number of recommendations for further research have been identified throughout this report. This section summaries those research needs.

8.5.1 Monitoring Indicators of Climate Change

It is recommended that current monitoring programmes should be reviewed holistically in light of their ability to elucidate to what extent climate change continues to happen within London. For example, actions to improve air quality in London cannot be considered in isolation from those designed to reduce greenhouse gas emissions. However, more attention needs to be paid to diffuse sources – in particular, those linked to the transport infrastructure. This could take the form of: new fiscal and voluntary initiatives to control emissions; traffic restrictions; improved public transport systems; incentives to promote carpooling; and pollution warning services (e.g. London Air Quality Network). Such endeavours should be underpinned by regional inventories of pollution sources, as well as by systems for continuous monitoring of key pollutants and relevant weather variables.

Rising ambient air temperatures in central London and concomitant increases in temperatures across the London Underground network have been raised as a key area of stakeholder concern. Although some data and model results are available for the new terminal at King's Cross, there are no long-term temperature records for the wider network. Until such monitoring systems are in place, claims of rising underground temperatures and possible links to climate change will remain largely anecdotal.

8.5.2 Modelling

The Thames Region Water Resources strategy used a range of scenarios that included potential climate change, to inform the development of the strategy. However, more work needs to be done to consider the impacts at the catchment level. The extent of probable impacts of climate change on the Thames water resource strategy can only really be answered through an integrated regional water resource modelling exercise, that incorporates more climate change detail within the Environment Agency's four socio-economic scenarios. Alternatively, research could be targeted at critical elements in the strategy, such as modelling the reliable yield of a new reservoir, or levels of leakage, under the full set of UKCIP02 scenarios.

The EA is developing Catchment Abstraction Management Strategies to assess the total amount of water available in a catchment and develop a strategic plan for supply and demand. Another process - the 'Restoring Sustainable Abstraction' programme is assessing other ways of obtaining water for supplying needs in particular areas. Both of these processes should be informed by the present study as well as seeking further ways of assessing the potential impacts of climate change on water resources for London. Statistical downscaling techniques could deliver the local, catchment scale scenarios needed to undertake these investigations.

The EA, working with a range of partners, is developing a strategy for flood risk management in the Thames Estuary for the next 100 years. The project is co-ordinated by the Thames Estuary Partnership. Its aim is to assess and understand the tidal defences in the context of the wider Thames Estuary setting. This includes assessment of the residual useful life of the defences together with an understanding of the 'drivers' including climate change, urban development, social pressures and the environment. The project will take five years to complete and involve research to build up a detailed understanding of the physical processes affecting the Thames Estuary. Again, statistical downscaling techniques could be used to develop scenarios of tidal surges that compliment existing work with physical models of the estuary. This project should also examine the potential for the use of open and green spaces for temporary flood storage. Research is also currently being carried out on the adaptation of urban drainage systems (see water companies section above).More research needs to be carried out on the relative significance of catchment land use and climate change.

8.5.3 Comparison with other Global Cities

The draft London Plan argues that it is most appropriate to compare London to other global cities such as New York, Tokyo, Paris, Berlin and so on. The very preliminary comparison of climate change impacts in Tokyo and New York carried out in this study, suggests that the adverse effects would be slightly greater than in London, at least in the current socio-economic conditions. Impacts upon other comparative European cities have not been evaluated. Our guess is that they would be broadly similar, though possibly with a smaller negative effect. The most robust conclusion to draw is that a preliminary comparison between competitor cities indicates that London does not face any significantly greater adverse or beneficial impacts than other cities. A more robust comparison between impacts on global cities is an important future research task.

8.5.4 Dams

The condition of dams in London should continue to be assessed (the Reservoir Act 1975). This should, and does, include consideration of the potential impacts of climate change on their performance.

8.5.5 Health and Climate Change in London

Further consideration and formulation of appropriate responses to:

- The potential contribution of climate change to increased incidences of poor air quality and its impact on the health of susceptible people;
- Impact of increased temperatures on levels of heat stress;
- The potential of the move to a more outdoor lifestyle to improve people's health;
- Ways of improving road safety in conditions of climate change for potential increased numbers of pedestrians and cyclists;
- Health education initiatives to warn of the dangers of more exposure to sunlight and appropriate preventative actions;
- Impact on vulnerable groups of climate change and their service needs; and
- Hotter weather can lead to an improvement in eating habits e.g. more preference for salads, fruit and vegetables etc. However, not everyone has access to these foods either because there aren't the right kind of shops near to them or because they can't afford them. Increased demand for such foods under climate change conditions should be one of the factors in examining ways of ensuring access to fresh and healthy food across London.

8.5.6 Biodiversity and Climate Change in London

Further consideration of the potential impacts of climate change on habitats, species and green and open spaces in London along with appropriate response strategies.

8.5.7 Emergency Planning

Development of systems and processes to respond to climate related emergencies e.g. flooding, damage to buildings and the natural environment, heat stress and outbreaks of food poisoning.

Climate change impact may occur concurrently, such as exceptionally high tides in conjunction with severe river flooding events, or may occur with other extreme socio-economic events such as a stock market crash and a flu epidemic at the same time. Emergency Planning Authorities need to consider the combined effect of such events.

8.5.8 Historic Environment

Further work should be carried out on the potential impacts of climate change on archaeology and historic assets. As they are a key factor in attracting visitors and the quality of life in London, efforts should be focussed on ensuring they are protected from any damage that may result as a consequence of climate change

8.5.9 Strategic Processes

Apart from the present study, the policy processes set out in section 8.3 need to be informed by the forthcoming study on climate change adaptation options and the other strategic processes highlighted in this section.

There is a need to develop appropriate strategies and action plans to respond to the opportunities that climate change may present including:

- Move to a more outdoor lifestyle - more social interaction, entertainment opportunities, pavement cafes and sporting events e.g. outdoor athletics, cycling races and triathlon.
- Promotion of the environmental goods and services sector e.g. renewable energy (solar and wind), flood protection and flood proofing, sustainable urban drainage systems (SUDS) through appropriate developments and support for appropriate businesses.
- Examination of the potential for more water based transport. The Thames runs past many commercial, tourist and retail areas and so London could be well placed to provide more water based transport. This could be a pleasant i.e. cooler alternative to the current transport options. It may also assist in integrating development options in the East with the central areas.
- Examine the potential for London to act as a centre for greenhouse gas emissions trading building on its strengths as a financial services sector.
- Use climate change as a topic in the national curriculum. Its multidisciplinary nature could prove interesting to pupils.
- Examine the potential to enhance and extend biodiversity habitats that will benefit from some climate change conditions. The development of the redundant reservoir at Barn Elms into the London Wetland Centre is a good example of an innovative solution that could act as a model for other biodiversity developments.
- Examination of the potential to develop and provide consumer goods and services that are adaptable to climate change e.g. more extensive use of fabrics that are both breathable and waterproof, solar powered appliances, water efficient appliances and plants tolerant of higher temperatures.

The London Climate Change Partnership has taken the first step in commissioning this study so we can begin to understand the many ways in which climate change may affect London . The next important step is to ensure that the effects of climate change, both good and bad, are built into the decision making process for London, allowing the city to prepare for these impacts and take advantage of any opportunities.

8.5.10 Engaging the Public

The general public are already beginning to make the link between severe weather events and climate change such as the heavy rainfall and flooding in the winter of 2000. It is impossible to say whether individual events like these are caused as a direct result of human induced climate change but they are consistent with results from climate models. A well planned approach to communication is needed to present the public with well-founded, appropriate and accessible information. They need to know what the issues are and what to do.

It is particularly important that the public understands what they can do in emergencies that may be related to climate change such as extensive flooding, poor air quality episodes and intense hot spells that could directly affect their health and safety. The needs of vulnerable groups such as the elderly, those whose first language is not English and people with disabilities should also be identified and addressed.

Education (both formal and informal) should be used to engage the public. Climate change can be an interesting topic for learning in schools and other less formal methods due to its multi-disciplinary nature. Many schools are already using climate change as a teaching and learning topic.

The LCCP will need to consider how it wishes to engage other social groups and stakeholders in London. This may require developing a broader Partnership.

8.5.11 Local Authorities

A survey should be conducted of London local authorities to assess whether and if so how much they have considered climate change and its potential impacts on their services. Asking them to sign up to the Nottingham Charter for Climate Change may help to focus their attention on the need to plan for climate change.

8.5.12 Buildings

Further work needs to be done on how both new and existing buildings can be designed or adapted to improve the living and working conditions under climate change. Issues that need to be considered include:

- Cooling and heating systems e.g. use of groundwater cooling, role of natural ventilation;
- Layout and landscaping of development to provide shading and necessary air flow;
- Appropriate materials e.g. appropriate levels of glazing and insulation;
- Flexibility - ability to adapt to future climate conditions;
- Flood defence/proofing and adaptation;
- Water efficiency measures; and
- Weather proofing.

The GLA are planning to develop supplementary planning guidance (SPG) on sustainable buildings. The SPG should put forward measures that will allow buildings to adapt to climate change.

8.5.13 Specific Developments

Further work should be carried out to examine, as far as possible, the specific potential impacts of climate change on strategic developments e.g. the Thames Gateway, along with the formulation of appropriate responses strategies, where necessary. Suggestions for adaptation options that may be appropriate are contained in the tables above.

8.5.14 Further Quantification of Economic Impacts

As a result of the link between the insurance and financial markets, the financial service sector may also be impacted indirectly by climate change related extreme weather events. The size of this impact will be determined by the extent that the insurance sector has been able to pass on risk to other financial institutions. It is believed that the policy of portfolio diversification which large financial institutions have will ensure that this risk will be reduced and the impact mitigated. This conclusion is not well established and needs to be supported by further research.

The economic costs of disruption to London transport systems was the economic impact most widely identified by stakeholders in the consultation process. Detailed modelling of transport flows to, and within, the city, in combination with climate change model scenarios, are required to accurately assess the likely extent of such costs.

Further work is required to clarify the net balance of change in energy demand as a consequence of climate change in London. The supply infrastructure network is vulnerable to windstorms and clay shrinkage. The economic impacts of disruption to the power supply for extended periods has not been estimated in quantitative terms but is believed to be significant.

Further work is required to clarify the uncertainty surrounding the net economic impact of climate change on tourism and leisure. Revenues may increase as London - and the UK - becomes a more attractive destination in summer relative to those in Southern Europe and elsewhere that are likely to suffer from adverse climate change impacts. However, more trips may be taken from London to escape, for example from uncomfortable temperatures.

9. Conclusions

9.1 Initial Study Findings

The climate in London, as measured by key environmental indicators such as air temperature, rainfall, snowfall, evaporation and relative humidity, river flow, groundwater levels, tidal levels, river water quality, air quality and biodiversity has changed during the 20th century.

The climate in London is expected to continue to change in the 21st century due, at least in part, to greenhouse gas emissions from human activities.

London has a number of unique and key features that could be vulnerable to the impacts of climate change: businesses like insurance and utilities will be likely to feel the strain as climate induced stress on infrastructure and built environment increases; the workforce will be affected by changes in transport, health and the nature of the working environment; culture, leisure and tourism sectors will face increased visitor and site management challenges; flood defences will probably have to be strengthened and water resource management reviewed; rare habitats and species may be threatened as the environment changes around them; the seasonality of energy demands will be likely to evolve with reduced demand for heating in winter and increased demand for cooling in summer.

As well as some of the threats of climate change identified above, during an initial stakeholder workshop held at the start of the project, a number of climate change related opportunities were identified. These included: an increase in outdoor lifestyles such as increased use of open spaces for "open air festivals" and an increase in cycling and walking which would reduce pressures on transport systems; the opportunity to develop sustainable houses and neighbourhoods; climate change as a driver for greater environmental awareness and action; increased demand for "green products and services" including renewable energy; increase in London's tourism and leisure markets; and new opportunities for carbon trading services.

9.2 Key Climate Change Impacts on London

- London may be particularly sensitive to increases in temperature in the future because of the urban heat island effect. Models show progressive increases in both summer heat island intensity and frequency with climate change. This will have detrimental effects on air quality, summer electricity demand (although there will be a reduction in demand for winter heating), and comfort in the city's buildings and transport network. By the 2080s, London's summer extreme temperatures could be comparable with those of present day New York.

- London is exposed to far greater potential damage from flooding than any other urban area in the UK - due to the value of its assets and the fact that a significant proportion of London lies within the floodplain of the River Thames and its tributaries. Whilst flood protection levels are presently good, in the longer term, unless current action to increase investments in flood management measures is continued, the increased risk of flooding from climate change could lead to damage to buildings and property and disruption of London's transport network. New developments to address the growing demand for housing will need adequate flood protection from all flood sources.

- The indirect costs of a perceived increased flood risk arise from relocation of business and commercial activities to other (global) cities and/or a relocation of highly skilled parts of the labour force, have not been quantified but are thought by stakeholders to be significant.
- Adaptation strategies for flood prevention are being developed. There is evidence of broad stakeholder involvement in this process though the process is at an early stage.
- London is one of the driest capital cities in the world, with available water resources per head of population similar to that of Israel. Climate change could reduce the amount of water available and increase demand in summer. Lower river flows in summer will raise water temperatures and aggravate water quality problems in the Thames and its tributaries, especially following summer storms.
- Poorer air quality that may result from climate change could pose serious problems for asthmatics as well as causing damage to London’s plants and buildings. Increased extreme temperatures could lead to higher levels of mortality related to heat stress. It has been estimated that the heat waves in 1976 and 1995 were associated with a 15% increase in mortality in greater London. However, higher winter temperatures would be likely to lead to a reduction in winter cold spell related mortality.
- Climate change could affect biodiversity in several ways. Warmer weather would favour conditions for increased competition from exotic species as well as the spread of disease and pests, affecting both fauna and flora. Rising sea levels could threaten rare saltmarsh habitats and increased summer drought could cause stress to wetlands and beech woodland. Earlier springs, longer frost-free seasons and reduced snowfall could affect dates of bird egg-laying, as well as the emergence, first flowering and health of leafing or flowering plants.
- Flood risk threats to buildings and infrastructure along with changing atmospheric conditions associated with a warmer climate present immediate challenges in building and urban design. These climate change issues do not relate only to London. There therefore appears to be a significant opportunity for London's established creative industries, particularly design and architecture, to capitalise on existing Sustainable City initiatives.
- The built environment may also be subject to subsidence that will worsen as clay soils dry out in summer and autumn. Alternate wetting of clays in winter and drying of clays in summer may cause increased ground movement resulting in increased potential for damage to underground pipes and cables. However, the building industry could benefit from an increased number of available construction days.
- London’s transport system and ancillary services are vulnerable to disruption from flooding and other extreme weather events that are expected to increase in

frequency and intensity. Increased temperatures on the London Underground, exacerbated by the urban heat island effect, will lead to passenger discomfort. Hotter summers may damage elements of transport infrastructure, causing buckled rails and rutted roads, with their attendant disruption and repair costs. However, higher temperatures will lead to a reduction in cold weather-related disruption.

- The economic costs of weather-related disruption to London transport systems was the economic impact most widely identified by stakeholders in the consultation process. Detailed modelling of transport flows to, and within, the city, in combination with climate change model scenarios, is required to accurately assess the likely extent of such costs. Historical analogues of a single weather-related disruption on only one stretch of the rail network suggest costs of broadly £2 million.

- The London insurance industry, as one of the three largest global insurance centres, is particularly exposed to an increased volume of claims from business and domestic customers that are likely to occur in the event of higher and more extreme wind storms and flood events. Since UK insurers offer greater insurance protection for weather-related damage than their competitors elsewhere, they are, consequentially, more exposed to climate change effects. As well as claims that may be made by those who have suffered damages to assets in London, there is a significant threat from claims that may be made by those in other parts of the world who are vulnerable to extreme climate change events (e.g. typhoons in South Asia).

- Catastrophic storms such as the 1987 windstorm can force insurance companies to sell some of their equity holdings including stocks and shares and property. This could lead to a fall in value of this equity, with a consequent deflationary effect on the economy. The inter-linking of international insurance and capital markets means that the wider financial service sector is likely to be impacted by both domestic and global extreme climate change events.

- Many households do not have adequate insurance cover, and this is more acute for those on lower incomes. This means the effects of flooding fall disproportionately upon these households, which increases inequality still further.

- However, there are significant business opportunities to the financial services sector arising from climate change for example, in the development of markets for catastrophe bonds and weather-related trading in the international financial markets. There are also opportunities from mitigation of greenhouse gas emissions, for example, in carbon emissions trading, energy auditing and verification consultancy.

- Manufacturing could be subject to disruption of raw materials (e.g. food stuffs) that are supplied from parts of the world adversely impacted by climate change. Consumer prices may then be expected to rise. The same mechanism may result in opportunities for recycling businesses, where the price of virgin raw materials (e.g. rubber, wood pulp) increases and makes recycled substitute products more competitive.

- Flood risks, transport disruption, and heat island effects are climate change impacts that might result in relocation of members of the workforce, or changes in commuting patterns. These effects might impact on the supply of labour to London's public administration, and other economic sectors.

- Increased temperatures could attract more visitors to London, benefiting the tourist sector. Leisure and recreational facilities and tourist attractions will need to be able to cope with climate change by providing a pleasant environment for visitors. However, high temperatures could lead to residents leaving London in search of a more comfortable environment on holidays or breaks.
- Climate change may cause changes in lifestyles. Outdoor living may be more favoured, although some members of society may be less able to take advantage of this due to lack of facilities locally, fear of crime or other forms of social exclusion. Green and open spaces will be used more intensively.

9.3 Policy Processes

There are a number of policy processes that are ongoing in London that will need to consider the potential impacts of climate change. The main strategy and policy processes related to climate change in London include:

- The draft London Plan - the spatial development plan for London;
- The London Development Agency's economic development strategy;
- The Environment Agency's strategic processes including those for water resources, flood defence (including flood warning) and water quality;
- Water companies' planning processes; and
- Emergency planning

Many of the key strategic and policy processes have begun to consider the potential impacts of climate change. Awareness of climate change issues amongst stakeholders involved in this study was high and is accelerating. However, most of the strategy and policy responses are of a scoping nature and more work needs to be done to begin to quantify the potential climate change impacts and adaptation options at the local level including impact on water resources, flooding, water quality, settlement patterns, employment, working conditions, open spaces, infrastructure, economic sectors, biodiversity, economic sectors, health and the built environment.

9.4 Concluding Remarks

This scoping study is the first step in the process of understanding the impacts of climate change on London and has:

- Identified the main climate change impacts and issues for London.
- Made recommendations as to how climate change should inform further policy and strategy development.
- Identified research gaps and needs.

- Engaged a wide range stakeholder views and raised further awareness of climate change impacts and issues amongst these stakeholders.

This scoping study provides a platform for LCCP to further engage stakeholders in the development of robust strategies and action plans to address the impacts of climate change on London.

Appendix A
The London Climate Change Partnership
1 Page

The following organisations have taken part in meetings of the Partnership during 2001:

Ashurst Morris Crisp Solicitors

Association of British Insurers

Association of London Government

British Waterways

Confederation of British Industry

Corporation of London

Cory Environmental

DEFRA

Environment Agency

Forum for the Future

Government Office for London

Greater London Authority

Hadley Centre, et Office

Housing Corporation (London Region)

J Laing plc

KPMG

London Development Agency

London Electricity plc

London Fire and Emergency Planning Authority

London First

London School of Hygiene and Tropical Medicine

London Tourist Board

London Waste

Thames Gateway London Partnership

Thames Water Utilities Ltd

UKCIP

Appendix B
Stakeholder Workshop Outputs

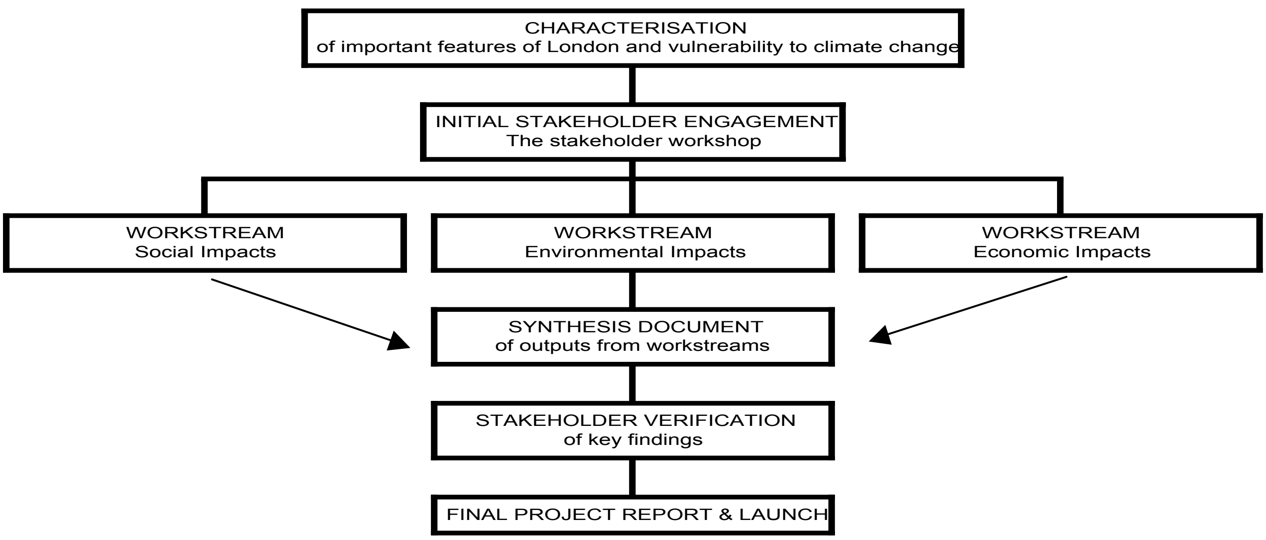
Stakeholder Engagement

Introduction

'Stakeholder engagement', a key objective of this study, is a broad term used to encompass (*inter alia*) the processes of: raising awareness amongst stakeholders; involving stakeholders; stakeholder consultation, and; consensus building amongst stakeholders. Stakeholder engagement has been addressed in several ways by this project but primarily through a workshop setting.

This section summaries the methodology used to engage stakeholders within workshops at two functional levels. These are represented in Figure 1 below which provides a summary of the overall project methodology. At the first functional level, an initial stakeholder workshop was held involving stakeholders selected from a broad range of organisations and interest areas. Subsequently separate smaller workshops and discussions were held on each of three themes or *workstreams* covering environmental, social and economic impacts of climate change. This section summaries the outputs from these workshops.

Figure 1 Summary of overall project methodology



Initial Stakeholder Workshop

Aim of the Workshop

The aim of the main stakeholder workshop was to highlight a broad range of issues around the impacts of climate change in London, from a variety of stakeholder perspectives. The information gained at this event was used to inform the project workstreams through prioritisation of key impacts for more detailed discussion and analysis and also to create stakeholder contacts for involvement in these workstreams.

The Stakeholders

The LCCP provided comprehensive lists of potential stakeholders for the workshop. These were combined with Entec's existing contacts and from potential participants recommended by the GLA. Over 150 stakeholder organisations were invited by e-mail to attend the workshop. Stakeholders invited were from businesses and organisations representing the following areas:

- Central Government;
- Local Government (planning and economic development);
- Environment and Sustainable Development;
- Transport;
- Health;
- Local partnerships;
- Housing;
- Utilities;
- Development and investors;
- Landowners;
- Construction;
- Insurance;
- Business and commerce (trade associations).

It was considered important to engage a range of stakeholders to provide a cross-section of views from across London. There was a great deal of interest in the project resulting in around 70 stakeholders attending the workshop.

Approach

Briefing material was provided to the stakeholders prior to the workshop, this included the following:

- Agenda;
- Characterisation of London (a document summarising the key characteristics of London and their vulnerability to climate change impacts); and
- Summary of UKCIP02 climate change scenarios.

A series of presentations at the workshop provided some background for the participants on climate change scenarios and their potential impact on London. This set the scene for the breakout discussion groups (a total of six discussion groups two groups for each workstream) that followed. During the breakout discussions, stakeholders were invited to:

- Identify the key social/environmental/economic characteristics of London;
- Identify potential impacts of climate change on London related to these characteristics;
- Prioritise impacts on London that they considered required further research;
- Expand and debate the priority impacts on social/environmental/economic aspects of London;
- Identify threats and opportunities for London presented by climate change impacts.

Key Impacts Identified by Stakeholders

The discussions that resulted provided a considerable amount of information and demonstrated a broad range of views. The key impacts discussed in detail are shown in Table 1.

Table 1 Key impacts identified by stakeholders

Social impacts	Environmental impacts	Economic impacts
Housing	Air Quality	Transport
Air Quality (Health)	Biodiversity	Business profiles
Built Environment	Flooding	Workforce
Migration	Water Resources	Wealth Generation

The impacts identified in Table 1 (and their inter-relationships) are discussed in detail elsewhere in this report.

Opportunities and Threats

Following the group discussion, individuals were given an additional opportunity to express personnel opinions on the impacts of climate change. This was achieved through a 'post-it note exercise' in which each delegate recorded their own views on the opportunities and threats which climate change would create and recorded them under social, environmental and economic headings. Key results are outlined in Table 2. These results were used as a primary input into each workstream workshop and are considered in detail in Sections 5, 6 &7.

Table 2 Summary of opportunities and threats identified by individual stakeholders

	Opportunities	Threats
Social impacts	More active outdoor lifestyles improve quality of life. Increase in cycling and walking will reduce strain on transport systems. New migrants will bring new skills and cultural richness particularly with regard to living in a warmer climate. Opportunity to develop sustainable houses and neighbourhoods.	Adverse health effects related to increased exposure to heat and UV-radiation. Potential for increased social disorder due to rise in temperature and associated stress. Environmental refugees, increasing the burden on the social/welfare state.
Environmental impacts	Climate change as a driver for greater environmental awareness and action: Sustainable Urban Drainage. Renewable energy. Positive review of environmental policy. Improved green space management.	Habitat loss with little opportunity for species migration due to fragmented habitat zones. Water stress - reduced summer availability for domestic, commercial, industrial and wildlife requirements (particularly wetlands). Increased incidents of flooding including sewer flooding.
Economic impacts	Increased demand for 'green products and services' including renewable energy. Increase in London's tourism and leisure markets. New opportunities for carbon trading.	Large impact on insurance industry - large pay outs, reduced cover, dented investor confidence. Mitigation funding and planning procedures are not in place. Will funding climate change (impact) mitigation adversely impact business or vulnerable areas of society.

Evaluation of Initial Workshop

Forty one of the participants completed an evaluation form after the workshop. The feedback, on the whole, was positive with the majority of people enjoying the workshop. Thirty seven of the participants completing an evaluation were interested in making a further contribution to the study through the workstreams. The evaluation results and comments are also provided in the Appendix.

Environmental Workstream

The Environmental Workstream Workshop held on the 10th May was attended by a broad range of delegates representing key organisations - including the GLA, Thames Gateway, London Development Agency, Thames Water, the EA and UKCIP. The workshop was designed to allow the stakeholders to consider the practical consequences of the UKCIP02 scenarios and to expand on areas of particular concern, highlighted at the main stakeholder event, within the context of environmental/water issues of London.

The workshop identified numerous groups that are already acting to monitor and mitigate the effects of environmental change in London and the South East. Notes from the workshop were circulated for approval and further comment, and the information consolidated in Section 5.

Social Workstream

The Social Workstream Workshop held on the 20th May was attended by a broad range of delegates representing key organisations - including the GLA, Thames Estuary Partnership, Transport for London, Forum for the future, the Directorate of Health and Social Care, and the Corporation of London. The workshop was designed to allow the stakeholders to expand on areas of particular concern, highlighted at the main stakeholder event, specifically social, political and cultural aspects of London life.

The workshop was based on a definition of 'social': "overall health and well-being, social and economic equity, public safety, public health and infrastructure, civil cultural and political society (including political institutions), and who bears the cost and reaps the benefits in future London." From this base the group examined three key areas in detail: flooding, higher temperatures; and impacts of climate change upon demography.

Notes from the workshop were circulated for approval and further comment and have been drawn together in Section 6.

Economic Workstream

The Economic Workstream output was based on a series of one to one interviews (meetings, telephone interviews and e-mail correspondence) conducted between the 10th-21st June. The sectoral stakeholders involved included representatives from Insurance companies (CGNU & D. Crichton), the National Grid, Thames Water, Business Services (Frost, KPMG), Environmental business, the London Tourist Office and Manufacturing industry. Notes from the interviews were circulated for approval and further comment and the results combined with information produced from an extensive literature review to produce Section 7.

STAKEHOLDER WORKSHOP

Seventy stakeholders attended a workshop on the impacts of climate change in London on May 1st 2002, held at the GLA offices in London. A series of presentations were made followed by small group discussions on the social, economic and environmental aspects of the impacts of climate change on London.

REVIEW OF IMPACTS OF CLIMATE CHANGE

For the discussion sessions the stakeholders were split into six groups. Two groups focused on social impacts of climate change, two groups looked at environmental impacts of climate change and two groups looked at economic impacts of climate change.

Each group was asked to:

1. Identify gaps in the characterisation of London presented by Entec UK Ltd
2. Identify impacts of climate change around the key characteristics of London
3. Prioritise two impacts they wished to discuss in greater detail (shown below as number of *votes*)
4. Discuss their chosen impacts in detail by responding to a series of questions

The notes made by group facilitators have been pulled together into the record of workshop outputs below. This will be used to inform the environmental, social and economic workstreams and the project report.

Group 1 - Social

Social Characteristics and related impacts

Population

- Will domestic energy use increase?
- Ageing - NHS (Heat wave warning systems) (1 vote)-
  - Social Care
  - Heat Stress *(1 vote)*
  - Institutional Care *(1 vote)*

Housing

- Density - Urban Heat Island *(2 votes)*
- Sustainable Build Regulations - old housing stock - Energy Efficiency - Air Conditioning *(4 votes)*
- Flood Risk - Great uncertainty

- Link to other studies - Thames Gateway - Thames Strategy East *(5 votes)*

- Sustainable Urban Drainage Systems (SUDS) - Heavy rain -> Damp, subsidence
- Services - Waste, water, power, education *(2 votes)*

Social Deprivation

- Fuel poverty *(1 vote)*
- Health - Respiration etc. *(4 votes)*
- Distribution of equitable impacts - variability of population *(3 votes)*

Ethnic Diversity

- Migration driven by Climate Change - political uncertainty
- London as gateway

Household Size

- Migrant households

Migration (additional key heading)

- Dispersal/migration of population resulting from climate change in other areas - ‘Refugees’ *(3 votes)*

- Health needs *(3 votes)*
- Economic mobility

Impact 1 - Migration

Discuss the consequences of this impact for London.

- Migration
  - Within London
  - Into London
  - Into UK via London
- Housing
- Economy/Employment/Skills - new people leads to new needs
- Services
  - Education
  - Health including new health needs
  - Infrastructure
- Social Exclusion
- Equity
- Out migration/Displacement
- Transport
- Skill pool

What information do we need to understand/measure/monitor this impact? - How might this be collected?

- Examine changes elsewhere - politically sensitive impacts of Climate Change on other countries
- 'Competitor Cities' - Economic migration, - Climate migration - To and From
- Past migration Patterns - Examine drivers
  - Push
  - Pull
  - Ask current migrants

What mechanisms and structures already exist to assess the issues?

- Greater London Authority (GLA)

- Past population census have been used to distribute resources
- NHS -> Migrant Health
- IPCC

Where or who is existing information coming from?

- GLA - growth predictions
- DTLR

In addition to climate change, what other factors can contribute to or influence this impact?

Policies

- Economic -> Predictions validity?
- Development planning
- Infrastructure
- Availability of services -> Water -> Power -> Health etc

Frameworks

- GLA

Other drivers of change or potential causes

- Migration within UK
- North/South divide
- Regional competitive report - DTI or DTLR

What tensions arise when you consider the other aspects of sustainable development related to this impact?

- Increased Development/Demand

Impact 2 - Built Environment 'Commercial'

Discuss the consequences of this impact for London.

- Housing
  - Flood
  - Heat stress
  - Commercial
- Productivity
  - Heat stress
  - Long lunches!

- Acceptable working conditions are variable with the external temp

- Occupational Illness
  - Heat stress
  - Long lunches!
  - Acceptable working conditions
  - Variable with external temp
  - Workforce obligations
- 'Physical Shock' - Move from regulated to unregulated temperature zones
- Residential
- Subsidence
  - Flooding -> People impact -> Depression -> Trauma etc.
  - Migration -> Choice where to live
- Land Values
- Preparation for extreme events
- Building Regulations
- Sewage Flooding

What information do we need to understand/measure/monitor this impact?

How might this information be collected?

- Look at other 'Hot Countries'
- Flood studies - where will houses be built after a 1 in 1000 event?

What mechanisms and structures already exist to assess the issues?

- EA

In addition to climate change, what other factors can contribute to or influence this impact?

Policies

- Working condition policies
- Building Regulations
- SUDS
- Flood plain building
- Frameworks

- Local Government implementation

Other drivers of change or potential causes

- Big floods
- Extreme heat waves
- Will developer pay for change

Group 2 - Social

Social Characteristics of London

Population

Housing

- Multi occupancy 500,000 new houses - will be flats!
- Characteristics of housing
- How housing is accommodated
- Smaller households - single occupier - small units
- What are the design elements needed to account for climate change?
- Cost implications from design needs
- Economics and market choice for size of house
- If moving toward multi-occupancy/communal space there are safety issues
- Construction raises safety issues
- Need proper management for social housing - build management issues into design
- Vulnerable to storm damage due to the way we live. This may promote a shift to increase densities of green spaces

Social Deprivation

Ethnic Diversity

- Cultural backgrounds changing service demands and needs

Recreation and amenity (additional key heading)

Education and skills and training (additional key heading)

Household Size

Health Inequality (additional key heading)

Impacts of Climate Change on London

- Transport infrastructure *(2 votes)*
- Water use for cooling underground - New technology
- Flooding (3 votes)
  - Flash floods
  - Drainage
  - Sewage

- Water table
- Air conditioning - cooling
- Energy demands *(1 vote)*
- Location of housing *(3 votes)*
- Design of housing *(7 votes)*
  - Flood plains
  - Street layout
  - Construction design
- Flooding properties
  - Bed-sits/Basement property
  - Vulnerable groups
- Subsidence
- Deprived groups/sector of community forced into poorer higher risk properties
- Fuel poverty
- Water metering - water poverty
- Poorer air quality *(5 votes)*
- Green space and parks *(3 votes)*
  - Recreation management
- More outdoor lifestyle improving health
- Damp property and drainage
- The impact on health of temperature changes *(6 votes)*
  - Respiratory problems
  - Hayfever
- Migration *(3 votes)*

Impact 1 - Air Quality

Discuss the consequences of this impact for London.

- Less attractive as a world city
- Impact on travel to work and working from home - Other local impacts
- Good or bad impact?

- Pollution concentrations
    - If Met. is increasing, high pollution episodes need a response, with traffic etc.
    - The loop related to energy use in air conditioning and emissions implications
- Potential out migration may have economic impacts on inward investment
- Concentrations of pollution in relation to population
    - Noise
    - Housing
    - Recreation
    - Exposure levels - Internal and external
- Knowledge gap exists, need more detailed resolution i.e. pollution in specific areas and specific streets
- Vulnerable groups, e.g. - Schools playtime, old people's homes

What information do we need to understand/measure/monitor this impact? How might this be collected?

- Identify existing controls - integrated planning
- Tie resolution models with emission inventory
- Need monitoring of outdoor air pollution
- Influence on planning decisions- demographics and hotspots

What mechanisms and structures already exist to assess the issues?

- Reporting of high pollution incidents
- Needs to be greater awareness - better publicised
- Comprehensive air quality network information exists
    - Healthy schools initiatives
    - Information is made available and used by asthmatic/respiratory sufferers

Where or who is existing information coming from?

- Imperial College - DAPPLE - air quality/modes
- University of Birmingham - in airport
- Internal
- LA have to produce Air Quality Plans and there will be a requirement to produce traffic plans

- London Health Observatory
- Department of Health and World Health Organisation

In addition to climate change, what other factors can contribute to or influence this impact?

- How much impact does traffic management actually have on air quality?
- Low emission zones
- International implication of particulate regulations, Kyoto and other international targets
- Shifting distribution in economic sector - e.g. manufacturing or farming! May increase in London what would the impacts be of this shift?
- Global cities - competition
  - Quality of life based, e.g. Edinburgh and Leeds are competitors, if they offer a better quality of life people will move there

Impact 2 - Housing

What information do we need to understand/measure/monitor this impact?

How might this information be collected?

- What happens to existing stock/level clearance/grants available
- Design for conditions in 100 years rather than now - building regulations, e.g. flood proofing

What mechanisms and structures already exist to assess the issues?

- Housing Association are able to 'design in' environmental and safety aspects whereas private housing doesn't as it is profit driven.
  - Economic
  - Choice
  - Markets
- Public sector should lead way on best practice

Where or who is existing information coming from?

- Construction industry are beginning to recognise Climate Change
- TCPA are doing some thinking around Climate Change
- EPSRC - impacts of Climate Change on the built environment
- BRE/CIFIA/Tyndall Centre
- Housing Health and Safety rating system - hazard issues

In addition to climate change, what other factors can contribute to or influence this impact?

- Ethnically diverse population and changing socio demographics mean new and changing expectations
- Community involvement and social regeneration
- Location of jobs in London and the south east
  - Commuting and migrating populations
- Business location and transport to/from/between work and home
  - Changing business practices
  - Work from home
  - Decentralised/multicentric business
- Global recession/war
- Government intervention
- Technology improvements - affordability of technology

What tensions arise when you consider the other aspects of sustainable development related to this impact?

- Capital cost - revenue cost
  - Cost to construction industry, running cost for home owner is rising
- Long-term changes in economic practice. What is considered as good practice now may be different in the future
- Sustainable development and environmental accountability
- Skills shortages - employers become more aware of importance of environmental and social needs
- Realisation from consumers, who want a good quality of life, that they as ‘drivers’ of markets will have to pay
- Inequality - social deprivation

Group 3 - Environmental

Environmental Characteristics

Water Quality

- Temperature of the Thames - fish, cooling
- Increased silt
- Less dilution capacity - low flows

- Differences due to seasons - resource implications

Flooding

- Public/corporate ‘education’
- Loss of fresh water habitats *(1 vote)*
- Impact on emergency services *(1 vote)*
- Long-term evaluation of flood defenses *(2 votes)*
- Impact on nearby landfill

Water Resources

- Supply/demand balance *(5 votes)*
- Water levels on fresh water wetlands
- Decrease of burst pipes

Air Quality

- More cooling needed - building and transport *(1 vote)*
- Impact on building fabric
- Benefits to pest reduction

- Affect of wind to improve air quality - people moving to outskirts

Biodiversity

- Dangerous species may increase e.g. Malaria
- Impact on reservoirs
- Distribution of species
- More people in outdoor areas

Waste Management

- IPPC
- Greater volume

Riverside Development

- Demand to live by the river
- Changes in physical Environment

Transport

- Exodus in the summer

Environmental Impacts of Climate Change in London

- Difficult to maintain quality *(1 vote)*
- Location of sewage works *(1 vote)*
- Impact of sea-level rise and flows to rivers
- Flood storm over-flows *(1 vote)*
- Algal blooms
- Flooding/protection of buildings *(6 votes)*
- Better design
- Insurance blight
- Protect flood plains
- Plans could improve environment
- Increased demand *(1 vote)*
- More in winter/less in summer
- Rising ground water *(1 vote)*
- Borehole cooling;
- Need to water green spaces - outdoor use
- More fires on scrub and health leading to decrease in air quality *(1 vote)*
- Smog/ozone have health impacts increasing pressure on Doctors and Hospitals *(2 votes)*
- Health less cold/fuel poverty *(1 vote)*
- Impact on habitats?
- Exposure - more outdoors
- Greater use of air conditioning
- Scrub/heath fires *(1 vote)*
- Requirement to protect SSSIs
- Loss of habitats *(3 votes)*
- Changes to habitats
- Changes to species
- Preservation Vs Conservation

- Landfill location by river
- Speedier rotting - Quicker collection
- Change in waste composition *(1 vote)*
- Increase re-cycling/composting
- Locations for disposal *(1 vote)*
- Available sites - but flooding? *(1 vote)*
- Properties set back from flood plain
- Properly already on flood plain
- Riverside defenses - more *(1 vote)*
- De-zoning of green belt to provide alternative sites?
- Need to cool
- London Underground - flooding?
- More walking/cycling? (unless increased rain)
- Facilities in the work place
- More need - waste/deliveries

Impact 1 - Flooding

Discuss the consequences of this impact for London.

- Flooding/protection of buildings - Graded Mapping of Flood Risk
- Causes:- a) Tidal flooding
  b) Watercourse Flooding
  c) Sewage flooding
  d) Localised shallow groundwater flooding
- Managed realignment
- Protection of buildings
- Design of buildings
- Long-term Flood Design Strategy
- Warning/Emergency Planning
- Insurance issues

What information do we need to understand/measure/monitor this impact? How might this be collected?

- Planning for flood risk project
- Thames Strategy East
- Strategic Environmental Assessment
- PPG25 Assessments (with EA)
- Sewer capacity

What mechanisms and structures already exist to assess the issues?

- Development Plans
- PPG 25
- Building Regulations (SUDS)
- SDP

Where or who is existing information coming from?

- Borough Appraisals
- EA for Flood Risk 1 or 2
- Water Company for flood risk 1 or 2
- Transport for London
- Developers, Association of British Industry

In addition to climate change, what other factors can contribute to or influence this impact?

- Migration - Common sense on habitats (sustainability)
- Developers/public awareness
- Greater flooding
- Condition of current assets
- Leakage issues
- Reliance on water-based sewer system
- Manage water resources better through increased enforcement e.g. -> SUDS - in building regulations?
- Fiscal Policy
- Culture - use too much water

- Water company Asset Management Planning (AMP) process

What tensions arise when you consider the other aspects of sustainable development related to this impact?

- Tensions are limits to growth
- Development areas have to be in Flood Risk Areas
- Historic/sacrosanct issues
- Impacts/flexibility of infrastructure
- Current unsustainable lifestyle
- Nation of gardeners (farmers)
- Culture/legislation
- Conflict between London and South East competition for resources
- Housing demand/targets

Impact 2 - Water Resources (supply and demand)

Discuss the consequences of this impact for London.

- Health & hygiene issues (less usage/sanitation)
- Extremes in water availability _ Price rises, water bills
- Less water for putting out fires
- Competition for space for storage
- Greater need for SUDS and water demand/efficiency management (metering)
- Utilise: Increasing G.W. as a resource
- Habitat changes
- London requirement for storage reservoir
- Effluent re-use - Reservoir, de-salination
- Food production/agriculture

What information do we need to understand/measure/monitor this impact? How might this information be collected?

- Current use/extrapolate
- Drier springs and wetter winters (understand the differences between the CC scenarios)
- Potential for SUDS - what 'types' most effectively applied to London
- Subsidies (cross-subsidisation?)

What mechanisms and structures already exist to assess the issues?

- Used to addressing these issues therefore structures should be in place - (certainty better adopted than for floods)
- Catchment Abstraction Management Strategies (CAMS) (EA) process

Where or who is existing information coming from?

- Water companies _ Strategic for use etc.
- EA (CAMS)

Group 4 - Environmental

Environmental Characteristics and Impacts of Climate Change in London

Air Quality *(4 votes)*

- Noise ‘aesthetics’ (identified as an additional characteristic)
- Not all transport sources
- Local/point sources (stacks)
- Diffuse-traffic, constriction
- Indoor and underground air quality
- Open window - more vulnerable to traffic noise etc.
- Nitrogen deposition
- Thermal inversions
- London impacts on surrounding areas e.g. more air travel
- Odours - smog - ozone rises as Temp rises
- More building - dust - VOC’s
- Dry ground - dust more fires - effects air quality

Biodiversity *(5 Votes)*

- Wetlands
- Water bodies
- Thames Estuary
- Gardens & garden escapes
- Pest control
- Fires - bracken?
- PPL’s expectations of parks etc. Ponds, water ?
- Rising climate space for species habitat fragmentation

- Impacts on national, international designated species
- Species rising - completion, dynamics
- Increased tourism pressure
- Brownfield - impact on biodiversity/habitats
- Soil erosion + tree damage

Water Quality *(4 Votes)*

- Drinking water quality
- River SLR/saline
- Ground proposing more deep levels
- Shellfish & human health
- Worsens more treatment needed but no room
- Hence - Intensive treatment
- Hence - Energy intensive
- Sedimentation - from upstream & in London

Flooding *(6 votes)*

- London Underground already being pumped
- Assets STW ‘standard’
- Convective storms in London
- Urban ‘flashy’
- Thames Gateway
- Coastal squeezes (also biodiversity)
- Flood defenses raised
- Access + visual affected
- How to manage - hard/soft higher defenses when they are breached catastrophe

Water Resources *(4 votes)*

- London depends on external sources (incl. reservoirs)
- Conflicts over use e.g. for drinking Vs nature conservation
- Rising groundwater - could tap into this - local treatment needed
- Winter storage?

- Resource = finite/reducing
- Demand increase with Climate Change - grey water storage/rainwater harvesting

Sewage

- Foul flooding cut across all sectors
- Urban area any building very disruptive + difficult

Waste Management

- All goes outside London
- Increased emphases on recycling more incinerators (air quality), re-use, landfills are full
- Increasing offices - paper and electronic equipment (computers)
- Contaminated land & ground water
- Contaminated in landfill sites

Riverside Development

- Air quality
- Odours/rats health
- Flooding
- Biodiversity loss
- Access

Transport *(2 votes)*

- Construction of schemes environmental impacts
- Storm damage
- Insurance
- Air quality
- Noise

Impact 1 - Air Quality

Discuss the consequences of this impact for London

- Cycling of carbon - 'human/animals (short time scale) % fossil fuel etc. - long time scale
- Sulphates - declining
- N-growing problem

- How will atmosphere chemistry change because of CC? (Imperial College)
- Athens - smog! Taste of things to come?
- Study air quality but not including CC?
- Sources - sulphates - Nitrates - smog - O_3
- Skin/Health impacts 'Point'
- Sun + Air Pollution
- Diffuse transport
  - Alternative modes - i.e. cycling
  - Work on feasibility of low emission vehicles/for areas in London
- Nitrogen - how will wet/dry deposition be impacted. Nitrogen enrichment on land, water and lighting
- Drier atmosphere increase dust with impacts on health
- If more construction dust will increase
- Hotter- open windows and spend more time outside - indoor air quality will be poor - dust mites survive easier. Air conditioning will increase

What information do we need to Understand/measure/monitor this impact?

How might this information be collected?

- EA & LA's do air quality monitoring - but need more!
- Need to understand air quality and climate change - modelling
- Network of automatic stations - need more of these including monitoring metrology
- Are we monitoring the right pollutants in the right places?

What mechanisms and structures already exist to assess this issue?

- Need to monitor & understand urban microclimate & e.g., street canyons
- Modelling needed - CC + air quality
- Will we have more exceeds of air quality standards?
- Integrate with air quality - managing strategies

Where or who is existing information coming from?

- Also monitor traffic - flow/condition/vehicle types
- Also monitor construction sites

- EA/LA's keep monitoring data for industrial processes

In addition to climate change - what other factors can contribute to/or influence this impact?

- Policies - air quality - IPPC, AGMS, NAQS
- Targets for traffic emissions Sulphur and Nitrogen protocols
- SOC economic changes in pollutant sources - e.g. traffic, waste strategies, energy policy, transport policy will affect extent if impact.
- Local community 'pressure' e.g. if odours from waste worsens more rubbish collection will be demanded
- Tourism changes may lead to traffic changes

What tensions arise when you consider the other aspects of sustainable development related to this impact?

- Always winners & losers. Must aim for net grain.

Impact 2 - Biodiversity

Discuss the consequences of this impact for London.

- Changes to species (flora/fauna composition habitats)
- Have to explain/educate people that change will occur - need to gain acceptance.
- Designated sites have more value and can be used to manage change
- Current debate in nature conservation world on managing change
- Parks (increased pressure on them) - Green spaces - physical climate
- Parks vital biodiversity resource in London - under pressure from tourism
- Use roofs as green space or for water storage etc
- Hamstead Heath - recreational uses different from Hamstead Common which is more nature conservation focused!
- Availability of green space in cities to allow species to move to new climate space.
- Do we restrict access to parks, to protect species threatened by climate change?
- Impacts of sea level rise on estuarine habitats and changing species composition - water bird numbers

What information do we need to understand/measure/monitor this impact?

How might this information be collected?

- Historical data - phonology - UK phonology network
- Engage public to do this - e.g. 'biodiversity network' being set up by Corporation of London

- Learn from climate change modelling studies - e.g. MONARCH
- Can't 'learn lesson' from other countries with similar climates - e.g. day length in UK doesn't change with Climate Change

What measures and structures already exist to assess the issues?

- Biodiversity Action Plans (BAP) consult on what populous value/should be protected through engaging the public (e.g. 'wildlife trusts') educate populous about climate change
- BAP process at all levels policies on the ground need to take account of climate change
- Habitats directive/birds directive/Ramsar don't currently take account of dynamic change should do! The water framework directive doesn't acknowledge dynamic system - no change!

Where or who is existing information coming from?

- English nature, Monarch funders and researchers
- Water sector contribute e.g. BAPs, LEAPS (EA + Water companies)

In addition to climate change what other factors can contribute to or influence this impact?

- CBD, FCCC, LA21
- Community Strategies (soon)
- Water quality
- Air quality
- Flooding
- Planning
- Transport
- Leisure
- Tourism
- Agriculture etc

What tensions arise when you consider the other aspects of sustainable development related to this impact?

- Planning/LU/USP's
- Need to know where goal posts are for nature conservation
- Do we accept climate change impacts or try to resist them?

Group 5 - Economic

Economic Characteristics and Impacts of Climate Change in London

Profiles

- Spatial characteristics
- Dynamic/changes *(3 votes)*
- More Home working!
- Impacts on Thames gateway + costs of protection
- London's position may improve in comparison to other cities
- Impacts on developing countries may have effects on London (e.g. migration)

Transport

- Commuting (9 votes)
- Increase demand for public transport
- Air Conditioning for modes of transport
- Increase in leisure travel
- Flooding disruption
- Greater measure for technological improvement - cycles and cars

Workforce

- Unemployment *(3 votes)*
- Employment opportunities in new technologies e.g. renewables - solar
- Consultancy opportunities
- Hotter climate may discourage manufacturing
- Seasonal and tourism employment

Tourism and Leisure *(4 votes)*

- May be more seasonal employment
- Floods may discourage tourism and leisure
- Overall trend is positive
- More outdoor activities garden/parks

Construction

- Heat island effects intensified with increased housing/development density

- Design and materials will change
- Flood plain issues
- Flood defense - SUDS

Government

- Effects how decisions are taken
- Big issue in London - (big for UK - London Centre)

Cultural Heritage

- Indoor tourism related to heritage becomes less attractive
- Could impact on design of buildings
- Historic buildings maybe more difficult to use/adapt
- More costly to maintain

Knowledge Economy *(1 vote)*

- Climate change studies will benefit academies
- Financial services study on issues - climate change

Wealth Generation *(8 votes)*

- Financial Services - insurance
- Investment changes
- Carbon trading skills
- London insurance capital of world - high risk to industry!
- Floods/hazards will have potential detrimental impact

Consumption

- Consumption of water may increase *(2 votes)*
- Increased energy consumption (and demand for) air conditioning, fridge's etc
- Depends on where goods come from material may change

Impact 1 - Transport

What information do we need to understand/measure/monitor this impact?

How might this information be collected?

- Draft London Plan, transport strategy and other strategies
- Environmental monitoring, risk analysis of impacts on transport

What mechanisms and structures already exist to assess the issues?

- Flood doors on tubes - functional?
- Bridge over viaducts - flood plains functional
- Maintenance systems checked reviewed for extreme events

Where or who is existing information coming from?

- Local authorities
- Transport plans
- Air quality monitoring
- Surveys e.g. British airports authorities

In addition to climate change, what other factors can contribute to/or influence the impact?

- Population increases
- Clustering tendencies for businesses
- Housing density
- Work patterns - technology dependant
- Infrastructure development - by rail, transport for London/highways agency
- Port authorities
- Airport development

Considering economic, social and environmental impacts, what are the opportunities and threats that may rise from the impacts of climate change?

- Push to travel less distance - work/home
- Mode shift - walk/cycle - sustainability
- Investment in cleaner transport - energy efficiency
- Social diversion in access to recreation

Impact 2 - Wealth Generation

What information do we need to understand/measure/monitor this impact?

How might this information be collected?

- Information on alternative investments + associated risks
- Evidence of climate change

What mechanisms and strengths already exist to assess the issues?

- Reliance on current EC reporting for Households - media

Where or who is existing information coming from?

- IPCC
- LA/EA on flood risk

In addition to climate change, what other factors can contribute to or influence this impact?

- Globalisation - Clustering effects
- Employment trends

Group 6 - Economic

Economic Characteristics and impacts of climate change in London

Workforce *(5 votes)*

- Working conditions and getting to work
- Population projections
- Migration as a source of new values social + economic
- More house working
- Discourage people from working late
- Does it exasperate inequality *(1 vote)*
- Depends on drain on welfare/special services

Tourism & Leisure

- Few hotels with air con at moment
- Change in type of tourism
- Water storage
- Could become more seasonal?
- Provision of more outdoor facilities
- Winters warmer but wetter - cloudier - could be positive

Economic Characteristics *(2 votes)*

- Level of capital assets at risk from climate change! Only from flooding
- Data could exist
- power supply
- Business interruptions e.g. underground
- Power supply telecom

<u>Profiles</u> *(4 votes)*

- Business costs - ventilation (3 votes)
- Discuss the consequences of this impact for London
- New GLA building borehole cooled
- Energy costs more - renewable increased opportunity
- Natural poor indoor air quality
- Corridors - new high buildings
- Building design outdoor e.g. Lloyds, register of shipping HSBC

<u>Transport</u> *(5 votes)*

- Heat stress more workers
- Public transport
- Impacts
- V hot tube
- 3 heat emergencies in Toronto. AC offices open to public
- Road gravel etc heat! Effects etc.
- Railtrack more leaves on track

<u>Cultural Heritage</u>

- Competitor cities

<u>Knowledge Economy</u>

- Water shortage *(1 vote)*
- Property prices *(2 votes)*
- Impact of floods risk on house prices
- Flooding + property prices
- Business impacts e.g. - manufacturing, watering?
- Does it help tall buildings

<u>Wealth Generation</u> *(1 vote)*

- Economic development issues
- London Plan
- Interruptions

- Business - transport + infrastructure
- Costs - Water - energy-land property
- Workforce

Impact 1 - Transport

Discuss the consequences of this impact for London

- Better weather more walking + cycling
- Showers at work - raise water use
- Shift from home to work
- Depends of proximity
- House prices
- Larger commuting
- Business locating in mixed use areas - live near to work
- Focus on East
- Open areas - access in London to outside
- Congestion changing to help with shift/outdoor lifestyle
- Actual interconnection between living locations + job locations
- Quality of walking/cycling experience Limit number of cars
- Working at house e.g. Sutton Meadway
- Changing in working patterns
- Other cultures - more renting/more flexibility
- Cycling pedestrians lower emissions problem + A & Q + bus lanes help
- River transport
- Speed/quality
- Interchanges

<u>Opportunities</u>

- Green chains walks
- Better use through better access
- What about using the issue as reason to make London transport (underground + air conditioning)

OPPORTUNITIES AND THREATS

Using post it notes, stakeholders gave their individual views on the threats and opportunities of Climate Change in London. The results of this are shown below.

ECONOMIC THREATS

- Insurance - Currently under writing losses are offset against investment income. Impact of climate change on investment returns - implications for premiums
- Reduced capitalisation/insolvency of insurance/mortgage lenders due to increased natural hazards.
- Threat to global reinsurance pool from global climate event claims (by 2050 > world GDP).
- Insurance industry leads to growing impact of extreme weather on insurance claims of some areas/activities becoming uninsurable.
- Major shift of economic and social enterprise away from London.
- Dented investor confidence if flooding message is not handled sensitively.
- Restrictions in emissions may lead to limits on economy growths.
- Damage to commercial and cultural buildings.
- Who will pay for additional infrastructure e.g. reservoirs? Will people pay today for the population of the future?
- The poor could pay proportionately more of the costs of climate change impacts.
- Inability of the planning process to respond to issues about developing of land at risk from flooding in the near future. Time lags.
- Fires and flooding will place an increased resource demand on emergency services.
- Possibility that public transport improvements do not keep track with climate change (e.g. air-conditioning) forcing people to use private cars more often.
- That London becomes fairly unbearable especially during long hot summers. Transport systems in particular will become unpleasant to use.
- Extremes of temperature may effect current transport systems in terms of location and frequency of use.
- Location of brownfield land and impact on supply - Greenwich: most brownfield land along river front. If that can't be developed for climate change reasons, supply will go down significantly.
- Increased energy demand and high energy prices leading to fuel poverty.
- Increased punitive legislation e.g. ROC, CCL.
- The £30bn flood event and knock-on effects.

ECONOMIC OPPORTUNITIES

- Sustainability - what happens to it? This is the over-arching and uniting factor that will help tie together arguments/actions from economic, social and environmental perspectives.
- Evening economy
- Products made from sustainable materials.
- Investment in more sustainable industries/activities.
- Need to distinguish between sectors that need to act in the short and long term e.g. restaurant owners - short, property developers - long.
- Increase in eco-economy jobs. New services such as climate change strategy, climate change consulting, green house gas auditing and verification. New need for environmental green collar market e.g. water recycling and solar energy.
- Increased maintenance requirements on housing may lead to new products offering servicing.
- Insurance opportunities - greater hazards lead to greater consumer demand. Longer life leads to increase in pensions/savings product demand.
- Opportunity to include environmental and social externalities in economic reasoning.
- People may become more resource efficient.
- Opportunity to develop real price for carbon related to environmental cost.
- Cut down on importing carbon fuels from abroad which equals better balance of payments
- Investment in renewable energy companies/technology due to high P/E ratio predicted.
- Shift towards less fossil fuel dependent transport.
- New markets: carbon trading weather derivatives.
- Development of alternative energies e.g. wind power.
- Employment in energy efficiency industry (development and manufacture).
- Increase amount of vegetated structures (through planning policy ad guidance) in built development to provide benefits for energy/noise limitation, air quality and therefore economic benefits (see Chicago and Canadian studies for cost savings on green roofs).
- Increase density and create new open space.
- Reduction in need to travel if new ways of doing business can be found.

- Improving transport e.g. tram links. Encouraging cycling and walking through development plans, community plans and by improvements to the urban environment. Improvements to the tube including East London line extension.
- New crops e.g. vineyards, olives and tomatoes.
- Opportunity for London to benefit economically from increased/new tourism opportunities
- That London becomes a relatively more attractive climate than other European cities e.g. Paris, Madrid, Rome i.e. it doesn't get as bad as they do.
- Potential reduction in long distance tourism.
- Tourism will benefit from hotter summers and milder winters, cleaner transport and green living.

SOCIAL THREATS

- Impact on economy of increased levels of occupational sickness or absenteeism as a result of temperature changes.
- Impact of temperature change implications on local health care provision.
- Health impacts of higher temperatures combined with air pollution etc e.g. asthma (air quality) skin cancers (sunlight).
- Increased health problems e.g. respiratory diseases from poor air quality - economic a social issue.
- Increased stress leads to increase in crime. Heat stress leads to instability, which leads to social unrest.
- Hot weather leads to open windows which leads to greater opportunistic burglary.
- Greater social disorder due to rise in temperatures leading to increased stress and arguments/conflict.
- Global trend leads to increased environmental refugee, which leads to increase in burden or social welfare/state.
- Fire - drier weather leads to greater vulnerability. Water shortage leads to problems pumping at incidents.
- Segregation of different social groups: ability to pay.
- Effects of fuel poverty.
- Effects of 'cooling' poverty leads to inequalities.
- Blight on homes/property in flooding areas.
- Health and safety impacts of flooding events (tidal, watercourse, sewer overflow). Effects of water shortages on aspects such as hygiene, gardening.

- Increased risk of flooding and associated disruption - impacts on development.
- Water metering and re-evaluation of our ‘free and unlimited’ view of water is essential.

SOCIAL OPPORTUNITIES

- Make society more aware of impacts of its actions and hopefully act to reduce consumption.
- Need to link to neighbourhood renewal strategies i.e. raise local awareness.
- New migrants can bring new culture.
- Greater demand for street café culture? (but inability of councils to deal with this).
- International immigration - Leads to new knowledge and skills including how to live in a hot climate.
- More outdoor activities/lifestyle and appreciation, picnics, sport, alfresco dining. e.g. better/warmer summers/springs/autumns
- Better national sporting performances due to warm weather training and greater opportunities to train.
- Longer motorcycling season.
- More outdoor leisure activities - better quality of life, better health.
- Increased cycling due to public transport avoidance (hot, cramped) (and private cars).
- Our social activities may change so we become healthier i.e. more outside activities, increased walking, cycling.
- Seriously revolutionise urban street networks to encourage cycling for recreation and community impacts on health air quality, safety, noise, well being.
- Wider variety of gardens, roof gardens etc.
- Restriction of development on flood plains will increase potential public open space.
- Improved attractiveness/equality for Londoners and immigrants by improved quality of life through imaginative investigations of climate change effects.
- Make more use of riverside developments along Thames corridor.
- Sustainable urban drainage/natural solutions often have beneficial effects on landscape and urban environment.
- Encourage jobs in developing and installing new technologies e.g. energy generation and use in buildings.
- Promote/link to need for co-operation on emergency planning issues.

ENVIRONMENTAL THREATS

- Environmental preservation needs to take precedence over short-term economic arguments.
- Fragmented habitats within London adaptation for species difficult without migration.
- (Planning policies could lead to) loss of habitat/species diversity, e.g. Loss of inter tidal habitats through 'coastal squeeze' and loss of designated habitats currently protected by sustainable defences.
- Over intense development causes increased noise/nuisance, poor access to open space, reduced diversity of habitats and species.
- Lack of water resource to maintain and re-create wetland habitats.
- Inflexibility of current conservation legislation (e.g. Habitats regulations) to adopt to changes.
- Habitat loss and therefore increase flood risk.
- Loss of habitat and erosion of environmental legislation (EU habitats directive).
- Loss of trees driven by an insurance industry which sees trees as economically damaging.
- Air pollution.
- Dust due to dryer climate in summer plus increased construction to accommodate new housing.
- Increased use of energy for cooling.
- Climate change could be overcome by social acceptance of improved/safer Nuclear Energy Generation possibly on a localised and modularised basis.
- Water contamination from sewers and flooding of landfill.
- Can water resources, rivers, flow, biodiversity be maintained/managed?
- Lack of water for say normal use WC's, basin, baths, taps. More importantly for fire fighting. Need to collect/save rainwater run off in the area it falls?
- Storm/flood damage occurrence.
- Increase in sewer flooding.
- Damage to historic and natural resources e.g. historic parks and palaces.
- Threat to existing character of area by higher densities/over development.
- Increased pollution as a result of increased road use - if public transport disruption.
- Threat on agricultural production - type of food types etc.

- In Central London positive feedback loop from air conditioning plant increasing air temperatures outside in the heat island.
- More Grass, heath and scrub fires in summer.

ENVIRONMENTAL OPPORTUNITIES

- Climate change as a driver to greater environmental awareness.
- Need to study the role of trees to demonstrate their benefits to the population.
- Role of tree planting to create shade, filtering of pollution etc.
- Reduced development on green field sites. Stem tide of decline in green spaces.
- Planning policies could help create new habitats leading to increased biodiversity.
- New habitat creation.
- Opportunity to 'internationalise' nature conservation agenda - shared objectives to accommodate shifting species (for e.g.).
- Encourage pedestrianisation of certain areas where transport links are good.
- More cycling and walking - hopefully less road congestion and raise health, less Public Transport congestion.
- Consideration of microclimates in design of development.
- Promoting use of water saving devices at the home especially hippos for toilets.
- SUDS (grey water retention/filtering) and better urban landscape.
- More use of rainwater storage for housing (make use of winter rain).
- Green roofs for: heat island mitigation (local cooling etc).
- Encouraging natural lighting and ventilation. Encourage sustainable building design through development plans. Encourage use of groundwater resources and recycling of 'grey water'. Encourage renewable energies and efficient use of resources.
- Managed realignment - Combined with imaginative design and construction of associated buildings - lifetime gains for developments, quality of life gains for occupants. Flood mitigation.
- Imperative for quality environment as housing density increases.
- SPG on sustainable construction and design (part of Mayor's draft London Plan).
- Sustainable building can also lead to an increase in quality building.
- Local protection/retreat of flood defences/imaginative construction and design.
- More sustainable design and integration of this information into planning mechanisms.

- Climate change could be overcome by social acceptance of improved/safer nuclear generation possibly on a localised and modularised basis.
- Integrating solar energy with mechanical ventilation and cooling to reduce peak energy demand and increase renewable energy.
- Increased opportunity for use of renewable energy sources e.g. solar power wind/wave energy.
- Hydrogen Fuel Cells - (hydrogen generated from natural gas in short term, renewable in longer). Delivering zero carbon. Efficient power, clean water securities of supply.
- Greatly improve air and environmental quality by using zero carbon fuels in transport and buildings e.g. Hydro power, photo-voltic.
- Change fuel usage from fossil to renewable in a major way in London e.g. wind and rooftop photo voltaics.
- More water resources to capture winter rain (reservoirs) - manage as wetlands and leisure facilities as well as storage.
- Could the research please take note of the importance of developing strategic environmental appraisal (SEA) techniques so that all plans covering London (especially the SDP) are properly evaluated in terms of their likely impact on climate change and response to it!
- Reduce fuel poverty in winter.
- To be more aware (data) of the quality of life in and out of work.
- Activities that reduce CO_2 emissions benefit health and environment raise air quality, decrease traffic and accidents, raise cycling and physical activities.
- More use of parks and all year round. More sport better for health.
- Promoting outdoor lifestyles - link to increase in physical activity - need to link to open/green space issues - biodiversity and impact of rise in pollution on health.
- Imminent change has got people together to address issues therefore better understanding of contributing.
- Restoration of multi-functioning river flood plains, providing flood water storage and environmental benefits.
- Create a Thames Park to allow flood protection in the Thames Gateway.
- Extend the Thames Path beyond the barrier to allow river terraces to be built.

WORKSHOP EVALUATION

Participants evaluated the workshop at the end of the session. The results are shown below.

Question	Response	Total respondents
To what extent do you feel this workshop has contributed to your knowledge and understanding of climate change impacts in London?	Not at all	
	Not very much	**3**
	Contributed little	**18**
	Improved considerably	**23**
How useful did you find the presentations?	Not at all useful	
	Not very useful	**2**
	Quite useful	**25**
	Very useful	**17**
How useful did you find the group work?	Not at all useful	**1**
	Not very useful	**4**
	Quite useful	**28**
	Very useful	**11**
How easy did you find it to contribute your ideas?	Not at all useful	
	Not very useful	**2**
	Quite useful	**25**
	Very useful	**17**
How enjoyable did you find the workshop?	Not at all enjoyable	
	Not very enjoyable	**2**
	Quite enjoyable	**28**
	Very enjoyable	**14**
Are you interested in making further contributions to study through the workstream research?	Yes	**37**
	No	**4**

Additional comments on the workshop made by participants are recorded below:

- I work on these issues so found the initial presentations facile - but understand that you have a mixed audience.
- Facilitation of group work wasn't too good and made worse by overcrowded noisy room and the questions that were posed, there were too many questions to answer not all of which really got at the key matters. The post it session at the end was useful to capture free ranging ideas.
- Acoustics poor for plenary sessions.
- Difficult to desegregate impact of climate change on London's economy of impact of responses to Climate Change on London's economy. Still unclear as to extent to when the two can be separated.
- The workshop had too many issues to cover. Sometimes the workshop leaders didn't seem as open to ideas as perhaps should (i.e. views were already formed). May have benefited from a smaller group size and separate room?
- Six break-out sessions in one room makes life very difficult unless interests developed very early. One major point that needs to be made is that the impact of

climate change is likely to be incremental in terms of its effects in problems that already exist rather than posing new problems i.e. London is essentially not sustainable.

- Geoff Jenkins presentation very helpful, others less so. Breakout sessions too long, too noisy.
- In the morning presentations, which were generally very good, there seemed to be an assumption that the audience was familiar with some of the technical issues and jargon.
- Facilitation could be better. Opportunity for ideas was stifled!
- The work of this group (Acchiles) is crucial. It will benefit from being 'joined-up' by attendance from most stakeholders.
- I found the venue rather difficult - difficult to hear/see initial presentations. Rather noisy in the workshops. Hope this could be addressed in future sessions? Otherwise a very useful and wide ranging morning - Thanks.
- I know that due to over subscription of people to groups you wished to allocate people. However, I think that maybe workshops should be allocated by a first come first serve basis so people have the opportunity to talk about areas that they are most interested in. This may generate more of a debate.
- Workshop very well organised (Emily did a great job in our group!) I look forward to receiving a report of the outcomes from the day.
- The space in which such a large group was required to undertake open discussion made it a little difficult to hear comments by other group members.
- Vast subject to cover in short period of time. Many other aspects to do with development of London and sustainable development touched on due to wide reaching effects of climate change and interests of stakeholders present.
- Very encouraging start to this project. Very good mix of people, all of whom were keen to participate.
- It was good to see representatives from a wide spectrum of organisations together in the same workshop. The people present not only represent a source of ideas but potentially a lot of information/data which could feed into the study.
- Workshop was well organised and run. A great deal of knowledge was displayed by participants and researchers. Increased my knowledge of (localised) climate change and possible implications quite considerably.
- Initial presentation by Entec a little basic - need deeper study.
- Background work should consider individual mayoral strategies and not just the (draft or consultation draft) London Plan - which does not contain the detail. For biodiversity, don't rely on English Nature's and RSPB's rural focus for telling us what we need to know about urban bio impacts. I am especially interested in

further study to examine multiple benefits offered by green roofs, energy, noise, water, air quality, cost, biodiversity, waste … all are relevant!

- Would welcome future workshops to examine the opportunities and potential (part or full) solutions to the impacts of climate change.
- In terms of the workshops, I would recommend tighter facilitation to ensure more efficient discussion and therefore raise quality outputs.
- Well done! Difficult to manage such a large group you made it very pleasant and informative.
- The presentations by Geoff Jenkins and Jim Kersey were excellent. (Are copies of the overheads to be made available?) A well planned/organised event. Thanks for the opportunity. The Climate Change Impacts Study should be part of a general Future Impacts Study. Climate change effects cannot be considered effectively in isolation.

WORKSHOP PARTICIPANTS

Amy Bahia	International Underwriting Association of London
Sarah Beuden	Southwark Council
Peter Brittain	Government Office for London
Dave Brook	DTLR
Alan Byrne	English Heritage
Jane Carlsen	GLA - draft London Plan
Tom Carpen	Greenwich Borough Council
Justin Carr	London Borough of Croydon
Simon Cartwright	Thames Gateway
Dr Sebastian Catovsky	DEFRA
Roger Chapman	Association of London Government
Matthew Chell	GLA
Richenda Connell	UK Climate Impacts Programme
Linda Collins	London Development Agency
Keith Colquhoun	Thames Water
Richard Coppin	London Borough of Redbridge, Energy Manager
Cameron Dash	London Borough of Lambeth
Dave Farebrother	Land Securities
James Farrell	GLA
David Fell	London First
Aleyne Friesner	GLA
Tom Frost	KPMG
Lucy Golding	Cross River Partnership
Andrew Griffiths	Chartered Institute of Environmental Health
Lesley Harding	London Development Agency
Mike Harley	English Nature
Vicky Hobart	NHS - London Region
Ralph Hodge	Ralph Hodge Associates
Richard Jackson	Confederation of British Industry

Geoff Jenkins	Hadley Centre, Met Office
Kirsty Johnson	London Borough of Hammersmith and Fulham
Catherine Jones	Transport for London
Petra Klemm	London Borough of Barnet
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Jon Lilley	Thames Estuary Partnership
Mark Lowers	London Borough of Havering, Energy Management
Shanti Majithia	National Grid
Jane Milne	Association of British Insurers
Simon Mills	Corporation of London
Olivia Morris	London First
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Dirk Paterson	London Chambers of Commerce
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Tim Reeder	Environment Agency
Simon Richards	Royal Parks Agency
Julia Ricketts	Department of Health
Jenny Rogers	Cory Environmental
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C Steenberg	London Borough of Richmond
Trevor Sumner	London Fire
Al Sule	Housing Corporation
Carrie Temple	RSPB
Joshua Thumin	GLA
William Trevethan	Corporation of London Planning Dept

Tim Walker	CGNU
Tony Winlow	Greenwich Borough Council, Energy Manager
Patrick Witter	London Borough of Sutton
Simon Young	London Fire

Appendix C
Representing Soil Moisture Variations Using the Hydrological Model CATCHMOD

In CATCHMOD a 'direct percolation' mechanism, allows fixed proportions (D_p) of incoming precipitation, that exceed the potential evaporation rate, to bypass the soil store (even during periods of soil moisture deficit). This process represents the observed behaviour of fractured soils and macropores during summer rainfall and is only relevant to soils overlying permeable strata. The soil moisture sub-model is based on Penman's (1949) drying curve such that when the supply of moisture is limited, evaporation occurs at a constant proportion, k, of the potential rate. The value of the soil moisture deficit above which evaporation occurs at the reduced rate, D_c, (termed the potential drying constant) is derived via parameter optimisation. The 'upper' soil horizon, therefore, has a finite capacity equal to this constant. The 'lower' horizon is depleted by the reduced rate only when the upper horizon is empty, and can accumulate large deficits (as witnessed during the severe 1976 UK drought). During recharge, wetting by precipitation fills the upper reservoir before any replenishment of the lower. When a basin zone becomes saturated excess moisture from the soil store contributes to total percolation. Where a soil is underlain by permeable geological formations, excess water from the overlying soil zone percolates through the unsaturated zone to the aquifer below.

GLOSSARY

Terms in *italics* are found elsewhere in this Glossary.

Aerosols Airborne solid or liquid particles, with a typical size between 0.01 and 10μm that reside in the atmosphere for at least several hours. Aerosols influence the *climate* directly through scattering and absorbing radiation, and indirectly through the formation and optical properties of clouds.

ALG Association of London Government

Anthropogenic Resulting from, or produced by, human beings.

Aquifer Layer of permeable rock, sand or gravel which allows water to pass through it and which if underlain by impermeable material, holds water to form a saturated layer or water table.

Atmosphere The gaseous envelope surrounding the Earth, comprising almost entirely of nitrogen (78.1%) and oxygen (20.9%), together with several trace gases, such as argon (0.93%) and *greenhouse gases* such as carbon dioxide.

Black box Describes a system or model for which the inputs and outputs are known, but intermediate processes are either unknown or unprescribed. See *regression*.

Climate The 'average weather' described in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organisation (WMO).

Climate change Statistically significant variation in either the mean state of the *climate*, or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or to *external forcings*, or to persistent *anthropogenic* changes in the composition of the atmosphere or in land use.

Climate model A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some its known properties.

Climate prediction An attempt to produce a most likely description or estimate of the actual evolution of the climate in the future, e.g. at seasonal, inter–annual or long–term time scales.

Climate projection A projection of the response of the climate system to emission or concentration scenarios of *greenhouse gases* and *aerosols*, or *radiative forcing* scenarios, often based on simulations by *climate models*. As such climate projections are based on assumptions concerning future socio–economic and technological developments.

Climate scenario A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships, that has been constructed for explicit use in investigating the potential consequences of anthropogenic *climate change*.

Climate variability Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events.

CSO Combined Sewer Outfall: - Structure which discharges effluent to watercourses when the sewage system becomes overloaded during periods of heavy rainfall.

Culvert A pipe or other covered passage under a road or railway, which carries a stream or drainage ditch. In the centre of some cities, small rivers that were important in the early development of the city are frequently enclosed in culverts and built over.

Deterministic A process, physical law or model that returns the same predictable outcome from repeat experiments when presented with the same initial and boundary conditions, in contrast to *stochastic* processes.

Domain A fixed region of the Earth's surface and over-lying atmosphere represented by a *Regional Climate Model*. Also, denotes the grid box(es) used for statistical *downscaling*. In both cases, the downscaling is accomplished using pressure, wind, temperature or vapour information supplied by a host GCM.

Divergence If a constant volume of fluid has its horizontal dimensions increased it experiences divergence and, by conservation of mass, its vertical dimension must decrease.

Downscaling The development of climate data for a point or small area from regional climate information. The regional climate data may originate either from a *climate model* or from observations. Downscaling models may relate processes operating across different time and/or space scales.

Emission scenario A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g. *greenhouse gases*, *aerosols*), based on a coherent and internally consistent set of assumptions about driving forces and their key relationships.

External forcing A set of factors that influence the evolution of the climate system in time (and excluding natural internal dynamics of the system). Examples of external forcing include volcanic eruptions, solar variations and human–induced forcings such as changing the composition of the atmosphere and land use change.

Extreme weather event An event that is rare within its statistical reference distribution at a particular place. Definitions of 'rare' vary from place to place (and from time to time), but an extreme event would normally be as rare or rarer than the 10th or 90th percentile.

Fluvial Riverine, pertaining to rivers.

General Circulation Model (GCM) A three–dimensional representation of the Earth's atmosphere using four primary equations describing the flow of energy (first law of thermodynamics) and momentum (Newton's second law of motion), along with the conservation of mass (continuity equation) and water vapour (ideal gas law). Each equation is solved at discrete points on the Earth's surface at fixed time intervals (typically 10–30 minutes), for several layers in the atmosphere defined by a regular *grid* (of about 200 km resolution). Couple ocean–atmosphere general circulation models (O/AGCMs) also include ocean, land–surface and sea–ice components. See *climate model*.

GLA Greater London Authority

GQA General Quality Assessment

Greenhouse gas Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. The primary greenhouse gases are water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3).

Grid The co–ordinate system employed by *GCM* or *RCM* to compute three–dimensional fields of atmospheric mass, energy flux, momentum and water vapour. The grid spacing determines the smallest features that can be realistically resolved by the model. Typical resolutions for GCMs are 200 km, and for RCMs 20–50 km.

GOL Government Office for London

LCCP London Climate Change Partnership

NCEP The acronym for the National Centre for Environmental Prediction. The source of re–analysis (climate model assimilated) data widely used for dynamical and statistical *downscaling* of the current climate.

Normalisation A statistical procedure involving the standardisation of a data set (by subtraction of the mean and division by the standard deviation) with respect to a predefined control period. The technique is widely used in statistical *downscaling* to reduce systematic biases in the mean and variance of climate model output.

OFWAT The Office of Water Services, responsible for making sure that the water sewerage companies in England and Wales give a good quality, efficient service at a fair price. They are a government department led by the Director General of Water Services.

Parameter A numerical value representing a process or attribute in a model. Some parameters are readily measurable climate properties; others are known to vary but are not specifically related to measurable features. Parameters are also used in climate models to represent processes that are poorly understood or resolved.

PPG25 Planning Guidance Note 25: - Local Planning Authorities are to ensure that flood risk is properly taken into account in the planning of developments to reduce the risk of flooding .

Predictand A variable that may be inferred through knowledge of the behaviour of one or more *predictor* variables.

Predictor	A variable that is assumed to have predictive skill for another variable of interest, the *predictand*. For example, day–to–day variations in atmospheric pressure may be a useful predictor of daily rainfall occurrence.
Radiative forcing	The change in net vertical irradiance (expressed as Watts per square metre) at the *tropopause* due to an internal change or a change in the *external forcing* of the climate system, such as, for example, a change in the concentration of carbon dioxide, or the output of the Sun.
Random	See *stochastic*.
Regional Climate Model (RCM)	A three–dimensional, mathematical model that simulates regional scale climate features (of 20–50 km resolution) given time–varying, atmospheric properties modelled by a General Circulation Model. The RCM *domain* is typically 'nested' within the three–dimensional *grid* used by a GCM to simulate large–scale fields (e.g. surface pressure, wind, temperature and vapour).
Regression	A statistical technique for constructing empirical relationships between a dependent (*predictand*) and set of independent (*predictor*) variables. See also *black box, transfer function*.
Relative humidity	A relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature expressed as a percentage.
Resolution	The *grid* separation of a climate model determining the smallest physical feature that can be realistically simulated.
Scenario	A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a 'narrative story–line'.
SDP	Strategic Development Plan.
Specific humidity	The ratio of the mass of water vapour (in grams) to the mass of moist air (in kilograms) in a given volume of air.
Station	The individual site at which meteorological measurements are systematically observed and recorded.

Stochastic	A process or model that returns different outcomes from repeat experiments even when presented with the same initial and boundary conditions, in contrast to *deterministic* processes. See *weather generator*.
Transfer function	A mathematical equation that relates a *predictor*, or set of predictor variables, to a target variable, the *predictand*. The predictor(s) and predictand represent processes operating at different temporal and/or spatial scales. In this case, the transfer function provides a means of *downscaling* information from coarse to finer resolutions.
Tropopause	The boundary between the lowest part of the atmosphere, known as the troposphere, and the highly stratified region of the atmosphere, known as the stratosphere. The tropopause is typically located 10 km above the Earth's surface.
Uncertainty	An expression of the degree to which a value (e.g. the future state of the climate system) is unknown. Uncertainty can result from a lack of information or from disagreement about what is known or knowable. It can also arise from poorly resolved climate model parameters or boundary conditions.
Weather generator	A model whose stochastic (random) behaviour statistically resembles daily weather data at a location. Unlike *deterministic* weather forecasting models, weather generators are not expected to duplicate a particular weather sequence at a given time in either the past or the future. Most weather generators assume a link between the precipitation process and secondary weather variables such as temperature, solar radiation and humidity.
Weather pattern	An objectively or subjectively classified distribution of surface (and/or upper atmosphere) meteorological variables, typically daily mean sea level pressure. Each atmospheric circulation pattern should have distinctive meteorological properties (e.g. chance of rainfall, sunshine hours, wind direction, air quality, etc). Examples of subjective circulation typing schemes include the European Grosswetterlagen, and the British Isles Lamb Weather Types.

Index

Note that where there is more than one page reference and one or two are considered more significant than the others, they are highlighted in **bold** typeface.

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This study was commissioned by the London Climate Change Partnership.

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This is one of a number of studies conducted under the umbrella of the UK Climate Impacts Programme (UKCIP). Based at the University of Oxford, UKCIP was set up by the Government in 1997, to provide a framework for an integrated assessment of climate impacts and to help organisations assess how they might be affected by climate change, so they can prepare.

This report and the more detailed technical report of the study can be found at **www.ukcip.org.uk/london/london.html**

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More information on climate change can be found at:
www.defra.gov.uk/environment/climatechange/
www.metoffice.gov.uk/research/hadleycentre/
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